John Henry Smith

SIXTEENTH ANNUAL REPORT

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PART II—PAPERS OF AN ECONOMIC CHARACTER.

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GEOLOGY AND MINING INDUSTRIES OF THE CRIPPLE CREEK DISTRICT, COLORADO.

IN TWO PARTS.

By WHITMAN CROSS and R. A. F. PENROSE, Jr.

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CRIPPLE CREEK, 1894; VIEW LOOKING NORTHEAST.

Mineral, Carbonate and Tenderfoot hills in the background.

GENERAL GEOLOGY OF THE CRIPPLE CREEK DISTRICT, COLORADO.

By Whitman Cross.

CHAPTER I.

INTRODUCTION.

FIELD WORK AND ACKNOWLEDGMENTS.

This report is principally based upon continuous field work in the Cripple Creek district from September 5 to November 24, 1894. In the course of mapping the Pikes Peak district, during the summer of 1893, about ten days were spent in the area embraced by this special map.

During both seasons the writer was ably assisted by Dr. E. B. Mathews, now instructor in petrology and mineralogy in Johns Hopkins University, Baltimore. The portion of the accompanying geological map without the border of the volcanic center, excepting Grouse Mountain, is mainly the work of Dr. Mathews.

The examination of the ore deposits of the district was carried on almost simultaneously with the investigation of the general geology, and the writer wishes to gratefully acknowledge the great assistance he has received from Dr. Penrose throughout the work.

GEOGRAPHIC POSITION OF THE CRIPPLE CREEK DISTRICT.

The mining district which is the subject of this report is situated in a group of, for the most part, rounded hills some 7 to 12 miles southwest of Pikes Peak, in the western part of El Paso County. It lies near the center of the territory embraced by the Pikes Peak sheet of the Geologic Atlas of the United States, issued in 1894.

The general elevation of the district is from 9,000 to 10,800 feet above sea-level. It is situated between Beaver and Oil creeks, two tributaries of the Arkansas River. The former, on the east, has several forks which rise in amphitheaters on the southern face of Pikes Peak, while Oil Creek, on the west, drains a large surface of the granite plateau west of the peak. The creek from which the town and mining district derive their name is one of the numerous branches of Oil Creek, which cut deep canyon gorges on their way to the main stream.

The climate of the region is arid, and vegetation is correspondingly scanty. Before the discovery of the gold mines the district was known only as a grazing country, as the names attached to several of the hills abundantly testify. The most striking feature of the country for some miles about Cripple Creek is the aspen growth, which has replaced a forest of spruce destroyed by forest fires many years ago. At the altitude of the mining district the aspens are often limited to the northern slopes, but toward Pikes Peak they cover large tracts, and finally give way to some beautiful dark forests of spruce, particularly on the western slopes of the mountain, and up to altitudes of over 11,500 feet. After the frosts of early autumn the aspen-clad hills seem fairly aflame with the brilliant yellow and orange colors of the turning leaves.

The mining camp is reached by wagon roads from Florissant and Divide on the north, from Colorado Springs on the east, and from Canyon on the south. Within the past year (1894) two railroads have been built into the district, one coming from the Colorado Midland Railroad, at Divide, on the north, and the other from Florence, on the Denver and Rio Grande Railroad, in the Arkansas Valley.

LITERATURE.

Prior to the discovery of the gold deposits now being worked the only publication concerning the geology of the Cripple Creek area was the Annual Report of the Hayden Survey for 1873. In this volume Endlich speaks in a most general way of a volcanic area south of Pikes Peak characterized by volcanic cones and flows of lava, and it may be assumed that he refers to the district in question.[1]

Since the gold discoveries of 1891 numerous newspaper accounts of the local geology have been given, and descriptions of mines and of the ores have been published in technical journals; but none of these has contributed to the general geology of the district to an extent deserving special mention.

After the field work upon the Pikes Peak district the writer presented a paper on Cripple Creek geology to the Colorado Scientific Society, which was published in pamphlet form in advance of the regular volume of the society's proceedings.[2]

CONDITIONS OF GEOLOGICAL WORK.

In all the central part of the area, where the hills are made up of volcanic material, there are but rare rock outcrops to aid the geologist in outlining the various formations. The slopes are usually smooth, covered with a scanty growth of grass or of aspens, or with a mantle of slide rock, effectually concealing the contacts of formations. The general character of the hillsides is well illustrated by the views shown in Pls. I, II, VIII, and IX.

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[1] Ann. Rept. Geol. and Geog. Survey of the Territories for 1873, p. 318.

[2] Geology of the Cripple Creek gold mining district, Colorado, read June 4, 1894.

Before the mining excitement had caused the opening of the thousands of prospect pits and trenches which now dot the slopes on all sides, it would have been impossible to have made a map of these hills having any great detail, and much is still lacking in regard to the boundaries of some of the important formations. Although prospect shafts are very numerous, they are often full of water, or caved in, or otherwise inaccessible; and while an inspection of the dump may show that several rocks were met with in sinking the shaft, their relations can not be ascertained. And while the camp is new it is by no means easy to get intelligent information concerning abandoned workings, nor is the obtainable information always satisfactory.

"Phonolite" has become a magic word in the district, and every prospector is sure that he has found it in his shaft. "Trachyte" and "porphyry" are also common terms, the application of which is sometimes highly original, as in the following instance: A certain phonolite dike, which was partly fresh and partly highly decomposed, was designated by a miner who had sunk a number of prospect holes in it "a belt of trachyte and porphyry." On being asked for his definitions of the terms, trachyte was described as "a blue-gray, hard rock," and "porphyry—well, porphyry generally runs three or four dollars" of gold to the ton. "Porphyry" is the term usually applied in the district to the bleached rocks, whether indurated breccia or massive material.

The greater part of the grading and cutting on the line of the Midland Terminal Railroad in the area of the map was done after field work had been finished.

GENERAL GEOLOGICAL CHARACTER OF THE DISTRICT.

The group of hills containing the mines of the Cripple Creek district are almost entirely made up of volcanic rocks, and the chief result of the present investigation is the demonstration that there is here a small vent in and about which the sequence of phenomena has been remarkably complete and typical of a true volcano. The principal material is fragmental, breccia or tuff, resulting from a succession of explosive outbursts. Massive rocks occur, representing in part bodies that have been largely destroyed in succeeding explosive periods of the volcano, and in part intrusive bodies of various sizes and shapes belonging to the later eruptions. Gaseous exhalations played a prominent part at certain periods, and in the final stage of the volcanic cycle hot waters circulated through the more or less permeable mass and decomposed the rocks to a great extent.

The history of the series of igneous magmas erupted at this center, as well as of the physical phenomena, has been that of a true volcano. The earliest rock was andesite, which was followed by a great number of eruptions of phonolite, the peculiarly characteristic rock of the center, at several periods, with explosive outbursts between them. As the last products of eruption, a number of highly basic rocks of varying character are found in small dikes.

The formation through which the Cripple Creek volcano burst and upon which its superficial materials lie is the granite-gneiss complex of the Colorado Range. In the immediate vicinity of the volcanic center these older rocks have been locally much altered by the agencies of the vent, but in general they are fresh and characteristic and contain many dikes of igneous rocks belonging to the phonolitic periods of the volcano.

GENERAL RELATIONS OF THE DISTRICT TO THE SURROUNDING COUNTRY.

In order to clearly explain the bearing of the geology of Cripple Creek upon questions of economic importance, it is necessary to present a sketch of the geological relations of the district to the area about it. The geological map and descriptive text of the Pikes Peak folio bring out most of the relationships, but it seems desirable to review in this place some of the features of greatest importance.

The hills of Cripple Creek lie near the eastern border of an uneven plateau, which stretches westward for 40 miles from the southern end of the Colorado Range to the low hills connecting the Mosquito and Sangre de Cristo ranges. It is true that the present surface of this plateau is much modified by canyons, hills, and low mountain masses, but a glance at the profile sections of the Pikes Peak folio shows how insignificant the minor variations appear in a broad view of the area. Moreover, it is not so much the plateau of to-day which deserves recognition as that which existed at the time of the volcanic outbreaks which formed the Cripple Creek hills; for the highest mountain masses of the area lying to the southward of South Park are also due to volcanic eruptions, probably in part synchronous with those of the smaller district to the east, and the canyons and depressions below the old plateau level are of still later date than the volcanic outbursts.

In the vicinity of Cripple Creek the granites, gneisses, and schists are exhibited in a very irregular and intricate mingling of types, and it is necessary to examine a large territory in order to understand much of this complication. The volcanic phenomena of Cripple Creek must be compared with those of the larger district in order to properly appreciate the natural limitations of the ore deposition in and about the volcanic center, as well as to indicate a natural field for future exploration. In respect to sedimentary formations, there is but little in the known history of the surrounding country which has any visible connection with that of the Cripple Creek district. The relations to the granite plateau and to the larger volcanic area will now be specially considered.

THE GRANITE-GNEISS COMPLEX.

Pikes Peak and the southern end of the Colorado Range are composed mainly of massive reddish granite, both coarse and fine grained. Southwest from the peak, toward Cripple Creek, bands of gneiss are occasionally met with, and the evidence that the gneisses are formed

from the granite on zones of shearing is locally very distinct. The field examination of the Pikes Peak area was necessarily too hurried to permit the tracing out of these shear zones, but they can be said to have a general north-northwest trend and to increase in importance to the westward.

Possessing a similar trend and extending from Cripple Creek to the Platte Canyon, on the north boundary of the Pikes Peak sheet, is a line along which the granite and derived gneisses contain numerous large and small included fragments of quartzite, quartz-fibrolite schists, or quartz-mica schists, and other similar rocks. A number of these are shown on the Cripple Creek map. This line is also in a very general way a boundary between predominant coarse-grained granite on the northeast and a later, fine-grained granite on the southwest. The number of the inclusions in granite is very great in all the district examined to the westward, as far as the line beyond which volcanics cover both.

In Wilson Park, about 14 miles south-southwest from Cripple Creek, is a notable mass of finely stratified, bluish quartzites, included in and penetrated by dikes of granite. These quartzites and others near Rocky post-office, in the northwestern corner of the Pikes Peak district, where fine conglomeritic layers occur, show that these granites have broken through and carried away in their masses many fragments of an ancient sedimentary formation, which is indeed at present known only in these fragments. From the evidence that Upper Cambrian strata rest upon these granites or their apparent contemporaries it has been concluded that the quartzite fragments belong to the great series of pre-Cambrian (Algonkian) sediments, to which remnants of ancient strata found elsewhere in Colorado have been referred. Hence the granites are not Archean, but are older than the only Cambrian rocks as yet identified in Colorado.

The igneous rocks of the Cripple Creek district are found resting upon or penetrating this complex of granites, gneisses, and included schist fragments, which are here micaceous or fibrolitic quartz-schists, and almost always much decomposed.

VOLCANIC AREAS NEAR CRIPPLE CREEK.

The volcanic center of the mining district stands at present quite isolated, but it is clear that it is to be regarded as a small outlying point of eruption, intimately connected with the region to the west, already referred to, in which outbreaks upon a large scale are proved by the complex of agglomerate, breccias, and tuffs, with intercalated lava-flows and intrusive masses of various kinds. During the field work upon the Pikes Peak sheet the eastern portion of the large volcanic area between the Arkansas River and South Park was examined in some detail. It is represented upon the Hayden map as chiefly of "trachoreite" with some basalt, and one small mass of andesite. In fact it

consists, in this eastern portion, of a series of roughly stratified breccias and tuffs of basaltic and andesitic rocks, more than 1,000 feet in thickness, with frequent dikes and intrusive or extrusive sheets of basalt, and later irregular masses and dikes of various andesites, rhyolite, and trachyte.

The fragmental volcanics rest upon a rolling floor of granite and gneiss, with the quartzite and schist inclusions described above. Erosion has removed a large amount of this material, and its former thickness and lateral extent are as yet matters of inference. As shown upon the Pikes Peak geological map, there are many remnants of this volcanic series east of the main area, preserved by massive lava-flows or filling minor hollows in the granite plateau. These remnants occur to within 6 miles of Cripple Creek on the northwest, and it is not improbable that at one time the fragmental materials of the Cripple Creek center mingled with those of the main district, the granite surface between them being entirely covered.

It appears certain that the chief source of the dark breccias and tuffs described was south of South Park, and although minor vents may have contributed locally, the evidence indicates that there was a principal center not yet accurately located. The rhyolites, trachytes, and later andesites seem, however, to have issued through innumerable fissures on all sides.

The small lake basin at Florissant, celebrated especially for its late Eocene (Oligocene) insect fauna, seems contemporaneous with the earlier part of the volcanic phenomena, for its beds are made up chiefly of fine volcanic dust and ashes, and are overlain by coarser breccia and by remnants of rhyolite flows. In High Park, 5 miles south of west from Cripple Creek, identical rhyolite flows were overlain by a local lake deposit, and these were in turn succeeded by phonolite masses. In this way a chain of evidence tends to show that the volcanic phenomena of this broad area belong to the Eocene period, possibly continuing into the Miocene.

RECENT PHYSIOGRAPHIC CHANGES IN THE REGION.

Since the close of the volcanic activity which has been briefly described, the granitic plateau and the volcanic accumulations upon it have been greatly modified by erosion. The region in question forms the watershed between the Platte and Arkansas rivers. The former traverses South Park, and leaves it at its southeastern extremity, in the northwestern part of the Pikes Peak district, and then turns abruptly to a northeasterly course across the Colorado Range to the plains. From this sharp bend it is about 30 miles nearly due south to the Royal Gorge of the Arkansas, the Platte being 2,700 feet higher than the Arkansas. As a result of this difference in elevation, the northern tributaries of the Arkansas—Current, Oil, Eight Mile, and Beaver creeks—have had much greater cutting power than those

of the Platte. They have removed much of the surface volcanic materials, and have carved deep canyons in the underlying granites and gneisses, so that on the Arkansas side the plateau feature which has been dwelt upon is recognizable only by the even elevations of many of the ridges between the canyons. Some of these tributaries have cut back to within 5 miles of the Platte at its bend to the northeast.

The Tertiary orographic movements which have resulted in this deformation are no doubt complex, the resultant being a general elevation of the mountain area relative to the plains, and one which seems to have been most pronounced to the north of the Arkansas River. But the study of the sedimentary area of Garden Park, which penetrates the plateau region from the south behind the Colorado Range, has shown that many local differential elements of the broader continental movement have played an important part in the present relation of the Cripple Creek district to the western plateau.

Garden Park Bay, as it may be called, is bounded chiefly by faults, upon which there has been a vertical movement of varying amounts in different places; but the chief displacement is on the eastern side, and increases northward, from zero opposite Millsap Creek to over 800 feet some 4 miles to the northward. It will appear, in discussing the geology of Grouse Mountain (see Chapter V), that there are grounds for supposing this fault to increase to a displacement of at least 1,200 feet opposite Cripple Creek, accounting for one of the most marked and sudden breaks in the plateau structure. By this fault the area on the east, including the entire district embraced in the special map, has been raised 1,000 to 1,200 feet. Other faults have doubtless had influence in producing some of the most distinct modifying features of the plateau country.

From the evidence which will be developed in describing the formations of Grouse Mountain it appears that the large fault above mentioned is of later age than the volcanic eruptions at Cripple Creek, and is thus probably Miocene or later.

CHAPTER II.

ROCK FORMATIONS.

GENERAL CLASSIFICATION OF THE ROCKS.

ROCKS OF THE FUNDAMENTAL SERIES.

Two general subdivisions of the rock formations of the Cripple Creek district may be made. One embraces the very old granites, gneisses, schists, etc., which constitute the main mass of the Colorado Range, and make the floor upon which the Paleozoic sediments rest, and through which igneous rocks have been erupted. With these may be included the narrow diabase dikes of pre-Cambrian age, which have nothing to do with the later eruptives.

These older rocks of the district belong to types which have been studied in the larger area of the Pikes Peak sheet. Many of their characteristics and relationships are not well shown near Cripple Creek, and as it is intended to publish a description of the geology of the larger area, these rocks are not treated in this chapter so fully as are those which are peculiar to the territory embraced within the special map.

TERTIARY ROCKS.

The second division includes the rocks erupted from the Cripple Creek volcano or found in the surrounding granite, but of evidently intimate connection with the volcanic center, and the deposits in a Tertiary lake basin. The treatment of the volcanic types will vary somewhat according to the importance of the different rocks. Thus, phonolite, the characteristic rock of the region, is present in many masses of somewhat differing development, and as it is, moreover, a very rare rock type in this country, it will receive a much fuller discussion than the more common and less interesting types of the volcano.

DESCRIPTION OF THE ROCKS.

GRANITE.[1]

Varieties distinguished.—The granites of this district are similar to those found in the area of the Pikes Peak sheet. Among them may be distinguished at least three well-defined types. The most prominent of these is that which has been called the "Cripple Creek granite."[2]

[1] The description of the granitic rocks of the area is taken from the manuscript of Dr. E. B. Mathews, now of Johns Hopkins University.

[2] The granites of Pikes Peak, Colorado, by E. B. Mathews, Bull. Geol. Soc. Am., vol. 6, 1895, p. 471,

This occupies the greater portion of the area immediately around the town. To the north may be seen the granite which seems to be especially characteristic of the larger area extending to and beyond Pikes Peak, whence the type receives its name. The third type is that which is common throughout the whole region in numerous narrow dikes.

Besides these three principal types, there are a few minor modifications, the most prominent of which are the peculiar red granite which forms the small hill on the south side of Spring Creek, opposite Red Mountain, and the variety adjacent to the town of Cripple Creek on the northwest.

Cripple Creek type.—The rocks included under this division make up the area west of the stream of Cripple Creek, and for a long distance west of the map line. The rock is a rather fine-grained, reddish biotite granite, in which the prominent constituent is an alkali feldspar, in lath-shaped, tabular, or short and stout crystals, a Carlsbad twinning being common. Quartz is present in bright-red grains evenly disseminated through the mass, the color being due to a marked staining by iron oxide. Biotite is, as a rule, not very abundant and not prominent, since it is scattered through the mass in small grains; but on the western border of the town the granite is locally different, containing biotite in abundance in large, clearly defined flakes, which seem to be fresher and more lustrous than elsewhere. This development of biotite at first suggests a further variety of the granites, but the fact that the feldspars preserve their short, stout habit makes it probable that this is only a local facies of the type under discussion. Biotite appears to be more richly developed in the zones about the included schist fragments than in the mass of the rock.

On microscopical examination it is found that the feldspar occurs chiefly in large, more or less automorphic individuals, which are apparently orthoclase and not microcline, as in many similar rocks of the Pikes Peak area. Plagioclase is present in subordinate amounts, and in the sections studied it is usually altered to kaolin or sericite. The alkali feldspar also occurs in the micropegmatite, which presents radiating or arborescent forms, near the large feldspar and quartz grains, with one of which there may be similar orientation.

Quartz is more abundant than in some of the other types, and it is especially distinct by reason of iron stains or inclusions. The large grains show some limonite in fissures. The quartz is often full of the inclusions which have been called "quartz-needles" and of small flakes of hematite.

Biotite occurs normally in large flakes rather than in aggregates of small ones, as is the case in much of the granite of the Pikes Peak type. Though apparently fresh, the microscope shows that the process of chloritization has gone on to a considerable extent. Muscovite is present as an original constituent, and when in connection with the biotite is seen to be older, giving to the latter its form and differing

from it in its orientation. But secondary muscovite is also present, derived from the biotite or from the feldspathic constituents.

Among the accessory minerals of this granite the more noticeable are zircon, apatite, epidote, and magnetite, all occurring in the usual manner.

Pikes Peak type.—This type occupies nearly all of the area north, east, and south of the volcanic center. The rock is coarse-grained and rudely porphyritic through large, more or less automorphic individuals of potash feldspar, usually microcline, which stand out most prominently on weathered surfaces. These rough phenocrysts are of a slightly pinkish color and often contain many small, black inclusions, probably biotite. The brachypinacoidal faces are best developed, and sometimes reach the size of an inch or two. The granular ground-mass consists of alkali feldspar, plagioclase, quartz, biotite, and sometimes hornblende. In many places the porphyritic structure is lacking and the rock is simply a coarse-grained biotite-granite.

The microscope shows that oligoclase, orthoclase, and what is probably secondary albite occur with the predominant microcline. In the great majority of specimens the predominant feldspar is microcline, which, with but a few minor exceptions, shows the usual twinning structure to extend equally across the entire individual. Sometimes when there are included mineral grains there may be a slight accentuation of the microcline structure about those inclusions, but in general there is no evident connection between the development of that structure and any deformation which the rock may have undergone. Further, there is perfectly developed microcline structure adjacent to quartz grains showing no undulatory extinction or other indication of pressure. Everything seems to point to an original development of the characteristic structure, and nothing seems to be contrary to such a conclusion. This statement refers to the larger grains of microcline, for the rocks carry small grains of evidently secondary microcline, which is clearly separable from the original. Plagioclase is less abundant than microcline and belongs to the oligoclase series.

Quartz occurs in considerable abundance, but is much less developed than the feldspar; it is always xenomorphic and in good-sized grains. Usually there is little evidence of dynamic action, though in the same granite beyond the area of the sheet there is abundant development of quartz mosaic and all of the phenomena due to crushing pressure. Generally the grains carry inclusions of iron oxide, rutile needles (?), and indeterminable fine particles of a green mineral with high double refraction. Micropegmatitic intergrowths are often present, frequently in great beauty, and are commonly connected with the contacts between the feldspar and quartz grains.

Biotite is but sparingly present in the Pikes Peak type, and appears in aggregates of small plates, the whole not much larger than the ordinary flake of biotite. It is often unaltered, with strong pleochroism in tones of reddish brown and yellow.

Besides the minerals described, there may be noticed occasionally small amounts of magnetite, hematite, rutile (?), hornblende, sphene, epidote, allanite, and fluorite.

Fine-grained dike granite.—The two granites above described and the schist masses included in them are traversed by many dikes of a fine-grained, reddish granite, composed of the same minerals as the earlier type, but differing from them in grain and in the equidimensional development of their grains, which are all xenomorphic and without crystal outline, except in the case of the early-formed ores and apatite. The intrusion of this fine-grained dike granite was considerably later than the eruption of the coarser types, as is proved by the fact that the Pikes Peak variety had already suffered deformation before the injection of this last rock, for gneisses derived from the earlier granite are cut by the fine-grained dikes.

Spring Creek variety.—There still remains to be described the peculiar variety which occurs opposite Red Mountain, on Spring Creek. The rock is of medium grain, has a more or less distinct porphyritic structure, and is marked by brilliant-red color, due to an exceptionally heavy impregnation of all the feldspar by iron oxide. Quartz appears in small irregular grains abundantly disseminated through the mass. No other constituents are visible to the unaided eye.

Under the microscope the striking feature is the clearness of the quartz grains between the deeply colored feldspars. The character of the feldspar is largely undeterminable, on account of the density of the hematite pigment staining it. It seems to be chiefly orthoclase.

Biotite was probably an original constituent of this granite, but it has been decomposed and mainly replaced by muscovite. An interesting element is fluorite, which occurs sparingly all through the granite. There is no indication that the fluorite has replaced any other mineral, and it seems probable that it here plays the rôle ascribed to it by Rosenbusch, of a druse mineral, filling the so-called miarolitic cavities.

SCHISTS.

Origin.—The schistose rocks of the Cripple Creek district belong to the great series of inclusions in the granites to which attention has been called in the introductory chapter. They are not so clearly metamorphosed sedimentary rocks as are many of the schists of the region to the west, but all these inclusions possess certain features in common, from which it must be concluded that they have been subjected to the same metamorphic action. It is quite possible that some, if not all, of the Cripple Creek schists have been produced from Archean gneisses forming the foundation upon which the Algonkian sediments were laid down. They represent so many varying modifications of a series that their description must be very general.

Description.—The schists in question are especially characterized by silvery muscovite and fibrolite, the latter being more variable than the

mica and not always present. Schistosity seems never very perfectly developed, but is always distinctly visible through the larger folia of mica, or the bands of dense fibrolite. Often the muscovite appears both in large plates and in very dense aggregates of minute flakes. Fibrolite is developed in most characteristic bundles of fibers, usually very thin but in many cases in isolated prisms, affording excellent material for study.

The schists of the body on the ridge northeast of Mount Pisgah consist almost wholly of muscovite, partly in large flakes and partly in a very fine-grained aggregate, with magnetite grains scattered all through it. The largest area of schists in the district, that lying northeast of Cripple Creek town, consists chiefly of fine-grained white mica schists, with much quartz, and in most cases a small amount of fibrolite. The quartz occurs in irregular grains scattered through the mass, as in a granite or gneiss, and is penetrated on all sides by fibrolite needles. Much of the muscovite is in fine aggregates of flakes, as if from replacement of a feldspar, and a small amount of kaolin apparently indicates the same former constituent. No biotite is seen in any of these rocks.

A rock which may properly be called a fibrolitic gneiss occurs on the ridge north of Grassy Gulch. Here an irregular granular mass of quartz and microcline feldspar, with abundant fibrolite of exceptionally large prisms, grades into a variety with mica replacing feldspar. Magnetite, limonite, and biotite make these rocks dark in color.

DIABASE.

The granites, gneisses, and schists of the Colorado and Wet Mountain ranges are cut by many small dikes of diabase and syenite which have not been observed to penetrate the Paleozoic sedimentary beds, and are hence probably of Algonkian or early Cambrian age. The diabase dikes are known to range from Devil's Head Mountain on the north to beyond the Rosita Hills on the south, more than 100 miles. They are especially numerous in the Royal Gorge and adjacent canyons, and may be distinctly seen from the car windows.

As a rule, the diabase of these dikes is of the simple ophitic type, but olivine-bearing rocks have also been observed near Parkdale, in the Arkansas Valley. The reddish syenites are especially numerous near Silver Cliff, and are often porphyritic.

In the Cripple Creek district a number of dark dike rocks have been found in the granites and gneisses. Their original composition is usually a matter of inference, for they are much altered, augite being entirely decomposed, with uralitic hornblende, chlorite, or calcite as products. Often the ophitic structure indicated by the feldspar crystals is the only guide in determining the rock.

The principal dikes of diabase represented upon the map are in the town of Cripple Creek or in the ridge to the northwest, and in the space

between Brind and Straub mountains. Many other small dikes are scattered through the region, but most of them can be traced only short distances.

PHONOLITE.

IMPORTANCE OF THE ROCK.

The peculiarly characteristic rock of the Cripple Creek volcano is phonolite. It occurs in dikes and in larger irregular masses, and is also a constituent of the tuffs and breccias of one of the explosive periods of the vent. This rock, moreover, occurs in many dikes in granite without the immediate volcanic center, and on all sides.

Phonolite is also a specially important rock in this district because it is closely connected with certain types of gold-bearing veins, as will be explained by Mr. Penrose in a subsequent chapter. From the general standpoint of petrology, too, these rocks are of particular interest, not only as belonging to a family very rare in the United States, but because their chemical and mineralogical composition is one especially suggestive in regard to the imperfectly understood laws which have operated to produce the great complexity of igneous rock types.

The material available for this study embraces specimens from nearly thirty masses of considerable size, including those of the area beyond the limits of the Cripple Creek special map, and from a large number of narrow dikes. The material is unusually fresh, excepting in the immediate volcanic center, and even there a few of the dikes exhibit some unaltered rock. On account of the excellence and importance of the material, it will be treated more systematically and fully than that of any other rock type.

GENERAL CHARACTER.

The phonolites of this region are all rich in potash and soda feldspars, and contain, as other characteristic minerals, nepheline, sodalite, nosean, and ægirine, or an allied augite. The accessory constituents, not always present, embrace analcite, lavenite, amphibole, biotite, titanite, magnetite, apatite, and a few rare and undetermined species. As a rule, these rocks exhibit the usual characteristics of the group, but certain varieties have interesting structural or mineralogical peculiarities, which will be specially described.

MINERALS OF THE PHONOLITES.

Feldspar.—All the feldspars of the phonolites, large and small, are, so far as observed, alkali feldspars. No single crystal of the common lime-soda plagioclase series has been found.

Glassy tabular phenocrysts are present to some extent in all masses, but they are seldom abundant. The crystals have a very good cleavage parallel to the predominant clinopinacoid, and flakes parallel to this face show an extinction relative to the basal cleavage line of about $+9^\circ$ to $+10^\circ$. No fine twin structure was visible in these flakes,

but sections of crystals in the rock slides sometimes show minute, spindle-shaped lamellæ of one or two systems, arranged as is characteristic of *anorthoclase*, although extinction is sensibly homogeneous in most cases. Where this structure is most distinct there is usually an outer zone free from the spindles, but full of gas pores, and even with a ragged outline interlocking with adjacent feldspar grains. Many phenocrysts have no visible structure suggesting a reference to any triclinic alkali feldspar, and it is believed that the phenocrysts of these rocks are predominantly *sanidine*, doubtless rich in soda, while *anorthoclase* is also developed in numerous cases.[1]

The minute feldspars of the ground-mass and of the small crystals of intermediate size found in a few rocks are apparently all referable to sanidine, though their nature can not be demonstrated. They are characteristically developed in staves and scales, exactly as in trachytes and in the well-known trachytic phonolites of Europe. A twinning according to the albite law is most common, but in some cases the Manebach law prevails. Elongation is parallel to the clinoaxis, and the optical character seems uniformly negative.

Nepheline.—This mineral is developed in these rocks in almost every degree of distinctness and obscurity known to the phonolites. It occurs in the characteristic short hexagonal prisms, varying in size from reddish phenocrysts of 2 mm. diameter in certain coarse-grained rocks down to those 0.01 mm. long, and in all but a few cases the trained eye experiences no difficulty in recognizing abundant grains of this constituent in the thin sections. Occasionally, however, in very fine-grained rocks the development of feldspar is less distinctly microlitic than usual, and here nepheline may be hidden almost completely, probably in part because it lacks automorphic development. This is true in some of the rocks which show a large percentage of substance soluble in cold hydrochloric acid and undoubtedly contain the usual amount of nepheline.

Nosean and sodalite.—The quantitative analyses of phonolites of this district all show the presence of sulphuric acid and chlorine, and from this fact one would naturally suppose that the rocks contained both nosean (or hauyne) and sodalite. And there are in reality two characteristic developments of minerals referable to this group in most of the rocks examined.

A majority of the phonolite specimens collected contain a few macroscopic crystals of rhombic dodecahedral form. They reach a maximum size of 3 or 4 mm., and range downward to less than 0.5 mm., but the microscopical study of thin sections shows the number of these crystals to be practically limited to what may be seen with a hand lens in the section. They contain a great many minute opaque inclusions, either making the whole mineral dark, or arranged in an outer border, or in

[1] In the similar phonolite of the Devil's Tower, near the Black Hills, Pirsson determined the phenocrysts as soda-orthoclase. Am. Jour. Sci. (3), Vol. XLVII, 1894, p. 342.

the diagonal lines characteristic of hauyne and nosean. A pale bluish or greenish color is sometimes visible in the fresh substance of crystals included in sanidine or nepheline. This mineral corresponds exactly to what has been called nosean or hauyne in many phonolites.

Contrasting with these large crystals, and often in the same rocks, there are minute crystals corresponding in size to the nephelines, visible only under the microscope, of hexagonal or square outlines, and uniformly isotropic, which usually contain a group of gas or fluid inclusions in the central part, while an outer narrow border is perfectly clear. Sometimes the substance is almost free from inclusions, but ordinarily the mineral in question is specially recognizable by their presence, for the accompanying nepheline apparently never carries them. There are no transitional forms between the large and small crystals of these two classes.

In the case of the minute crystals of many of these phonolites their recognition by the eye is a question of practice, for they are often so small and so nearly free from inclusions that only by becoming accustomed to their characteristics and associations can their identification be carried out. Very similar particles occurring in the phonolites of the Black Hills were interpreted by Pirsson[1] as sodalite, mainly because of the chlorine contents (0.15 per cent) of a rock analyzed. And such is the identification suggested by various circumstances connected with the series of rocks under discussion. The rock from east of Big Bull Mountain (see analysis, p. 39) contains no visible phenocrysts of the nosean-like mineral, and it is this rock which has the least amount of sulphuric acid. It is also true that the supposed sodalite is very difficult of detection in this rock, but that is true likewise of nepheline, although the rock is certainly a phonolite.

The rock containing the highest amount of chlorine has many minute crystal grains (0.04 mm. in size), seemingly of the sodalite mineral, but not well characterized by inclusions. As the two minerals lie side by side, the microchemical method used by Osann[2] for distinguishing the substances in question was tried with success. A thin section containing a comparatively fresh nosean (?) crystal 2 mm. in diameter and a large number of the minute sodalite crystals with very clear outer zones was covered with dilute acetic acid (20 per cent acid) to which chloride of barium had been added, and was allowed to remain under a bell glass for several hours, together with a watch glass containing the same solution, so that complete evaporation should not take place. Both minerals were attacked, and the nosean crystal was rendered cloudy and opaque by the precipitate of sulphate of barium, while the minute sodalite crystals remained perfectly clear. To confirm this test a quantitative determination of chlorine in this same rock was made by

[1] Phonolitic rocks from the Black Hills, Am. Jour. Sci. (3), Vol. XLVII, 1894, pp. 341-346.

[2] Neues Jahrbuch für Mineralogie, etc., 1892, Vol. I, 224.

Dr. W. F. Hillebrand, and 0.54 per cent was found. This amount corresponds to 7.4 per cent of sodalite in the rock, on the basis of the accepted formula for the mineral, and this does not seem at all too high, considering the abundance of the minute crystals described.

Ægirine and ægirine-augite.—The pyroxenic constituent of the phonolite is all ægirine in a majority of cases, but augite of grass-green color is very often associated with it.[1] Most commonly the augite appears as a core to irregular prisms whose outer zone is ægirine, and between the two is a zone of transitional optical character. These relationships are in no way different from those which have frequently been described in recent years in similar rocks.

The formal development of ægirine is extremely varied. Its most common form is as a cement for minute nepheline crystals or feldspar staves. In this form it is often so thin as to be very pale green in color, and would be indeterminable except for the evident gradation into larger particles. Fine needles of ægirine occasionally wrap around sharply defined nepheline crystals, or the structure becomes ophitic by orientation of ægirine over small areas. In this way there develops a transition to a common form of the ægirine, as a grain elongated parallel to the prism, full of included nepheline and feldspar crystals, and with an outer zone which reaches out among the adjacent mineral grains as an oriented cement. It is frequently the case that the growth beyond the comparatively solid core is mainly on the ends. Sheaf-like bundles of curving and forking ægirine needles occur in some rocks, usually in the denser varieties, and the forms assumed are sometimes very delicate.

Crystals of ægirine large and distinct enough to be macroscopically visible occur in many rocks, but the microscope shows them to be full of inclusions, and while the planes of the prismatic zone may be sharply defined, the terminations are usually irregular. In the rock from Grouse Mountain, however, the sharp pyramidal planes usually developed in this mineral are very clearly present in the prisms lying all through the mass.

Ægirine crystals of perfect form and free from inclusions are found projecting into the minute drusy cavities of certain rocks or embedded in analcite, which often fills these pores wholly or in part. In the coarse-grained porphyritic rocks of Grouse Mountain pure ægirine crystals are either attached to the large nephelines or penetrate them. The ægirine of these phonolites commonly possesses the characteristic pleochroism and optical orientation of the species, but occasionally colors are observed which belong to the acmite variety. The augite usually has a clear, grass-green color and a pleochroism increasing in intensity as the optical orientation approaches that of ægirine.

[1] The statement of the writer that hornblende was a prominent constituent of the phonolite bowlder previously described by him (Proc. Colo. Sci. Soc., Vol. II, p. 167) was entirely erroneous. As in many earlier statements, the identification rested solely on color and the small angle of extinction. Reexamination shows that the supposed hornblende is ægirine.

Blue amphibole.—In three phonolites of the Cripple Creek region there is a peculiar mineral whose specific character has not been definitely established, but which, from the properties to be described, appears to belong in the interesting group of amphiboles rich in soda and ferric oxide, now becoming known as widely distributed in very alkaline igneous rocks. This mineral has its best development in the ledge rock at the southern extremity of the Bull Cliff phonolite mass. The rock containing it is very dense, dark-green in color, mottled with lighter spots. Nepheline and feldspar are developed in such minute particles that their distinction is difficult, but ægirine appears abundantly in crystals whose prism and orthopinacoid faces are sharply defined, while the terminations are irregular. Though full of minute inclusions, the ægirines are isolated and scattered very regularly through the mass.

Corresponding closely to ægirine in manner of distribution is a rather dull-blue mineral in short, stout prisms, with never-failing low terminal planes, apparently domes or pyramids. These little crystals, of very uniform development, measure 0.10 to 0.15 mm. in length, and average 0.06 mm. in thickness. Sections normal to the prism have an almost hexagonal form, due to a pinacoid and a prism whose angle is more than 120°. Extinction here occurs parallel to the pinacoid. Prisms which seem to lie parallel to this pinacoid show inclined terminal outlines, inclined extinction, and a certain dichroism. Prisms seemingly normal to this pinacoid have a different dichroism, extinction parallel to the prismatic axis, and a rectangular, or at least symmetrical, termination. The symmetry is similar to that of a monoclinic amphibole, with unit clino- and orthodomes as the terminal planes. The outlines of the termination, as seen in apparent clinopinacoidal sections, make angles with the vertical axis and with each other which agree very closely with those of the basal plane and positive orthodome of amphibole.[1]

Assuming the monoclinic symmetry for the mineral, the optical orientation is as follows. The axes $\mathfrak{a}$ and $\mathfrak{c}$ lie in the clinopinacoid, $\mathfrak{a}$ being inclined at about 24° to $\dot{c}$. Pleochroism: $\mathfrak{a}$=deep grayish-blue, $\mathfrak{b}$=dull olive-brown, $\mathfrak{c}$=yellow. Absorption: $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$. The absorption is strong, but much less so than in arfvedsonite or riebeckite. Both single and double refraction are rather high. The optical character was not determined.

The properties given ally this mineral with the dark-blue iron-soda amphiboles, of which arfvedsonite and riebeckite are the best-known forms, and to which group may be assigned without hesitation the blue amphibole found by the writer as a secondary formation replacing or added to brown hornblende or diopside, in certain rocks of the Rosita

[1] References to the crystal form and optical orientation of amphibole assume the crystallographic position of Tschermak, adopted by Dana, whereby the basal plane and positive orthodome of former general usage are transposed.

Hills, Colorado,[1] and a form recently described by Palache[2] from Berkeley, Cal., to which he gave the name crossite.

In all of these minerals it is the axis $\mathfrak{a}$ of elasticity which lies near $\dot{c}$. The mineral from the Rosita Hills was originally described as near riebeckite, because at that time the orientation of arfvedsonite was not definitely known. But it has now been established by Rosenbusch[3] and Brögger[4] that the axis $\mathfrak{a}$ lies in the acute angle β, making an angle of 15° with $\dot{c}$. This orientation is also that of the Colorado mineral, and it has been considered as arfvedsonite by Rosenbusch, Brögger, and Dana. In the absence of chemical data this reference could not be questioned, but Palache has given an analysis (by Smith) of the mineral named crossite, showing it to contain a large admixture of the actinolite molecule (MgO=9.30 per cent), while ferrous and ferric oxides are nearly equal. In the Berkeley amphibole $\mathfrak{a}:\dot{c}=13°$, or nearly as in arfvedsonite, and if, as seems most probable, $\mathfrak{a}$ lies in both cases in acute β, the two minerals present very nearly identical optical orientation with decidedly different chemical composition.

From present knowledge of the chemical and molecular constitution of the amphiboles, we are not able to satisfactorily explain the variations in optical orientation of different varieties, and the Berkeley amphibole shows that the optical characteristics of the group which has been briefly discussed occur in varieties having a wide range of chemical composition.

Concerning the mineral found in the phonolites, it would seem probable that it corresponds in chemical composition more closely to the Berkeley amphibole than to arfvedsonite, on account of its color and absorption, but the very low amount of magnesia in the phonolites generally makes it likely that this base is here replaced by lime.

The blue amphibole developed in the magma at about the same time as the ægirine. While its crystals are always terminated, they are as much filled by minute colorless inclusions as the ægirine. Both these minerals and the one next to be described (låvenite?) are more or less arranged in streams expressing a fluidal structure parallel to the dike walls.

Låvenite?.—The same phonolite from Bull Cliff, in which the blue amphibole is best developed, contains another mineral whose identity is not completely established. It occurs in minute needles, colorless or pale-yellowish, isolated or grouped in loose bundles, and marking the fluidal structure of the rock by their arrangement even more plainly than the ægirine. The needles reach a length of 0.1 mm., by an average diameter of but 0.015 mm. They seem round in prismatic cross-section, but in a few cases appear to be octagonal.

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[1] Note on some secondary minerals of the Amphibole and Pyroxene groups, Am. Jour. Sci. (3), Vol. XXXIX, 1890, p. 359.

[2] On a rock from the vicinity of Berkeley containing a new soda-amphibole, University of California, Bulletin of the Department of Geology, Vol. I, 1894, pp. 181–192.

[3] Die mikroskopische Physiographie der petrographisch wichtigen Mineralien, 3d ed., 1892, p. 565.

[4] Die Gesteine der Grorudit-Tinguait-Serie, 1894, p. 33.

This mineral has rather high indexes of single and double refraction. In certain needles extinction takes place parallel to the prismatic axis, and in such cases there is no definite dichroism. In other needles an oblique extinction, reaching a maximum of about 18°, is observable, and here there is a strong, clear, yellow color for the axis nearly normal to the prism, while that near ċ is colorless, as before. The axis of least elasticity (c) is that inclined 72° to ċ, and it appears to be a which is near ċ. From these data it would appear that the mineral is monoclinic, with optic axes in the plane of symmetry. A twinning parallel to the vertical axis is often present in sections with inclined extinction. The extinction is greatest when the twinning line is sharpest, and is then equal on either side of the latter; hence the twinning plane is apparently the orthopinacoid.

In the phonolite with macroscopic nephelines, from the hills southwest of Cripple Creek, there are somewhat larger particles of låvenite than in the rock of Bull Cliff; but save for pleochroism they are generally less suitable for study than the smaller needles, on account of their irregular form. One prism, however, shows polysynthetic twinning parallel to the orthopinacoid and a pale greenish-yellow color parallel to a.

In the properties that have been given, this mineral agrees very well with låvenite, as developed in the phonolites of the Haute Loire in France, according to A. Lacroix,[1] although the needles are somewhat larger in the latter case, and hence much more strongly colored. It is observable in the phonolite of Bull Cliff that the intensity of color increases very rapidly with increasing thickness, and in the largest crystals an orange shade becomes perceptible. The only låvenite which has been available for comparison in this study is that in nepheline-syenite of the Kola region in Russian Lapland, described by Hackmann,[2] of which thin sections were kindly loaned the writer by Prof. L. V. Pirsson. The mineral is beautifully developed in some of the Kola rocks, but in so much thicker crystals that the intense pleochroism, varying from brilliant yellow to bright orange, can scarcely be compared with the feeble color of the needles in these phonolites.

There is a general resemblance between the delicate prisms of the Cripple Creek phonolites and several other mineral species which have been described from similar rocks, especially rinkite and the hainite[3] of Blumrich, both of which have been described from phonolites. The latter is triclinic in crystallization, however, and the optical orientation seems to sufficiently distinguish låvenite from rinkite. Its double refraction is also much higher than is that of rinkite.

In the rock from Bull Cliff the låvenite is present in all gradations down to needles which show only a faint yellow tinge parallel to c, and

[1] Bull. Soc. fran. de min., 1891, Vol. XIV, p. 15.

[2] Das Nephelinsyenitgebiet auf der Halbinsel Kola, von Wilhelm Ramsey und Victor Hackmann, Fennia, Vol. XI, No. 2, pp. iii + 225, Helsingfors, 1894.

[3] Die Phonolithe des Friedländer Bezirkes in Nordböhmen, von Jos. Blumrich, Tschermak's Min. und pet. Mitth., 1893, Vol. XIII, p. 472.

it is clear that still smaller ones would be sensibly colorless. From this fact it appears most probable that a colorless mineral, found in many other phonolites in the region, either in needles, in irregular jagged flakes, or in particles exactly analogous to the ægirine in its rôle of a matrix or cement for nepheline and sanidine, may also be referable to låvenite. The substance in question occurs side by side with ægirine, in the same development, but is clearly distinguishable in most cases, as the ægirine must sink to even greater thinness to lose its grass-green color completely.

The identification of this mineral as låvenite receives strong support from the chemical analyses of these phonolites, given on page 39. Dr. Hillebrand found determinable amounts of zirconia in every case, but the mineral zircon is very rarely present in thin sections. Brögger regards låvenite as allied to the pyroxenes, and shows it to contain about 30 per cent of zirconia.

Analcite.—A large number of the Cripple Creek phonolites contain an isotropic substance which is probably in all cases analcite. Its identification is most positive in the drusy rocks to be described, where the icositetrahedral crystals, colorless or of light-yellowish shade, are sharply defined. From these crystals there may be traced in various rocks all transitional stages of development to the irregular patches in solid rocks. In all cases the mineral of thin sections is colorless, traversed by irregular cracks, of high refractive power, and wholly isotropic. The crystals of ægirine and nepheline adjoining the analcite patches are automorphic, and the former is always better developed and purer in substance when penetrating the analcite than in any other relation.

The minute yellowish crystals of the drusy phonolite from Nipple Mountain were tested by the Boricky method and yielded abundant crystals of sodic silicofluoride.[1]

In describing the rock structures the question of the formation of analcite is especially discussed, and the conclusion is reached that it must be regarded as a primary constituent of these rocks, in the sense that it is not derived from the decomposition of any other constituent and was formed in the last period of crystallization of the magma.

Other minerals.—Magnetite is often entirely lacking, but it is sparsely distributed through half of the rocks examined. Whenever it becomes markedly abundant ægirine is correspondingly less prominent, a relationship agreeing with observations in other phonolites.

Biotite appears in very small flakes in two rocks only. A brown, slightly pleochroic mineral, apparently an amphibole, occurs in one rock. A colorless mineral resembling zircon, but having a high extinction angle, occurs included in the larger nephelines of a few sections.

Titanite, apatite, and zircon are occasionally present, but by no means so abundantly as in many other acid or intermediate rocks.

[1] Micro-chemical tests of this analcite were kindly made for me by Dr. E. C. E. Lord, of Washington.

Olivine appears in the phonolite of a dike in Rhyolite Mountain in large grains surrounded by reaction rims of magnetite and biotite. It is described in the discussion of the inclusions in the phonolites (p. 37).

MINERAL COMPOSITION AND STRUCTURE.

Character of the group as a whole.—The phonolites of the Cripple Creek district possess in general the characteristics most commonly considered as essential to the group in the schemes of classification now current. They are chiefly composed of alkali feldspar and nepheline, with sodalite and nosean, and a pyroxene rich in alkali and iron. The variations in chemical and consequent mineralogical composition are slight compared with the structural and textural modifications which arise from the differences in conditions of occurrence. The development of the minerals under the conditions which prevailed in this district has produced some structural types not often found.

A strong preponderance of the alkali feldspars causes a dominant trachytic or microlitic structure, and the general character of the mass is not changed, whether the pyroxene be ægirine or augite, while the nepheline, sodalite, etc., do not vary enough in quantity to cause distinct varieties. The description of the phases assumed by the rock will be adequately brought out by considering the structural forms assumed.

Schistosity.—All the dense phonolites possess a pronounced schistose structure, due to the fluidal arrangement of the more or less tabular feldspars, large and small, parallel to the walls of dikes. In large masses the structure is marked only near the walls, but in no case does the structure become entirely irregular. Where the minute feldspars are prismatic microlites their arrangement in planes still produced a decided parallel structure in the rock. Many of the phonolites are very fissile on account of this structure, and may be easily split into thin flakes with the hammer, while talus slopes are made up of more or less tabular fragments, from the same cause.

The much decomposed phonolite dikes of the volcanic center can be distinguished from those of andesite by the schistosity. In these decomposed rocks and on the weathered faces of fresher masses the parallel arrangement of the minute feldspar scales produces a delicate satiny luster or sheen.

The dense rocks.—While few of the masses of phonolite are entirely free from occasional large crystals of feldspar, of nosean, or of pyroxene, there are, on the other hand, few that are characteristically porphyritic in structure from the abundance of these crystals. Many of the rocks are of a uniform dull-green color, caused by the exclusive development of the ægirine in minute grains or as a cementing substance for the feldspar microlites. These rocks, especially, often have a dull, oily luster and a subconchoidal fracture.

The variations from the even dull-green color of the denser phonolites are mainly due to the development of the pyroxene. If it forms distinct grains or prisms of macroscopic size the rock appears speckled, but seldom comes to resemble a finely granular rock, because of the ragged interlocking borders of the pyroxenes and the existence of minute grains in the feldspar mass. When the pyroxene forms the larger aggregates, and especially when in sheaf-like bundles, inclosing nepheline and feldspar, the mass appears light-green, mottled by dark-green spots. The mottling and secondary coloring due to bleaching and decomposition are not considered here, but only the appearance of the fresh rock.

Porphyritic modifications.—As has been stated above, the phonolites are seldom pronounced porphyritic rocks, through the presence of feldspar phenocrysts, although slabs split parallel to the schistosity usually show a few glistening cleavage faces of tabular crystals, 1 cm. or less across. Feldspar phenocrysts characterize the phonolite of Nipple Mountain, 5 miles south of Victor, and several dikes in and about Bull Hill are unusually rich in them. The coarse-grained phonolite of Grouse Mountain, described below, contains feldspar phenocrysts in varying abundance.

Were it not for the inclusions which render the nosean crystals dull and not easily distinguished from the dark mass of the denser phonolites, there would be many rocks of quite noticeable porphyritic structure through the development of that constituent. As it is, the nosean ordinarily appears distinctly only when it has become white through decomposition. Dark, dull crystals of nosean, several millimeters in diameter, are noteworthy in the large phonolite masses of Big Bull Mountain, Little Pisgah Peak, and Mitre Peak, at the mouth of Wilson Creek. A rock very rich in dodecahedral crystals, probably referable to nosean, was found as a small remnant southeast of Nipple Mountain, but so extremely decomposed that its character could not be further determined.

The most noteworthy structural variety of the phonolites of this region is that due to the development of *nepheline* in numerous macroscopic crystals. The rocks thus characterized form a distinct type, observed in several localities, particularly in Grouse and Rhyolite mountains, the hill adjoining the town of Cripple Creek on the southwest, and in parts of the Straub Mountain mass, south of Lawrence.

In all of these cases nepheline is very abundant in uniform, short, prismatic crystals from 0.5 mm. to 2 mm. in diameter, which, by reason of their reddish color, stand out from the white, microlitic feldspathic ground-mass in which they lie. The color and luster are as in elæolite, and from the same cause. Ægirine is commonly developed in especially pure and well-formed prisms adjoining these nepheline crystals, sometimes penetrating them, but more commonly as prisms lying parallel to the outlines of the nepheline or in irregular grains penetrated by angles of that mineral. Tufts of ægirine sometimes radiate from the

surface of the nephelines or from the larger ægirine individuals. In all cases the nepheline is largely automorphic and of one period of formation, while ægirine, though chiefly later than nepheline, was in part contemporaneous with it, or earlier.

The ground-mass of these porphyritic phonolites is still microlitic, and exhibits fluidal structure in relation to the large nephelines. A portion of the nepheline is occasionally found in the customary microscopic crystals in the ground-mass. In all of the masses the rock with large nephelines grades into the customary fine-grained fissile form near the contacts, and there is no reason to assume that the phenocrysts of nepheline represent crystals of the so-called "intratelluric period." All the evidence seems to indicate that they were formed at or near the present site of the masses containing them.

One feature of these phonolites, which are porphyritic through the development of nepheline, seems of special interest and importance, namely, the evident local richness in *soda* of the spots in which these crystals develop. This is shown by the fact that the ægirines adjoining these nephelines never have cores of augite and are exceptionally strong yellow in color. They are also much purer and freer from inclusions, and sometimes have perfect terminations. The perfection of crystal form and purity is found, however, only when the prisms are embedded in an isotropic colorless mineral, supposed to be analcite, which often occurs in irregular patches adjoining the nephelines, like the filling of miarolitic pores. There is nothing in the occurrence to imply that the analcite is here a product of the decomposition of earlier-formed minerals, as is usual with zeolitic species. Prefectly fresh nephelines project into or seem sometimes surrounded by analcite. This occurrence of analcite is so plainly related to that in the drusy rocks, next to be considered, that a special discussion of the question as to the significance of analcite is left until the other rocks containing it have been described.

The development of other constituents in the phonolites containing large nephelines does not vary greatly from that in the average of these rocks. Feldspar phenocrysts are not more abundant, except in certain parts of the Grouse Mountain mass, nor are the noseans, while sodalite remains a constituent of the feldspathic ground-mass.

Låvenite appears in the hill southwest of Cripple Creek in grains somewhat larger than in any other rock, and in consequence shows the strong yellowish color and a perceptible pleochroism more distinctly than elsewhere. A mineral much resembling zircon in form and strength of both single and double refraction, but extinguishing at nearly 45° from the prism axis, was observed in numerous inclusions in nepheline crystals. By weathering out of the nephelines on exposed faces of this coarse-grained phonolite a pitted surface is produced.

The occurrence of nepheline in macroscopic crystals is stated by both Zirkel and Rosenbusch to be comparatively rare in the phonolites, and

from the descriptions they give of instances where it has been found it would appear that the above-described rocks of the Cripple Creek region are unique in the abundance of large nepheline crystals.

Drusy phonolites.—Several of the larger masses of phonolite, especially those of Mount Pisgah and Nipple Mountain, are, in part, somewhat porous in texture. The pores or druses are always small and irregular, flattened out and contorted in the general planes of imperfect schistosity. They are seldom continuous for more than one or two centimeters, and are very narrow, but the drusy texture thus produced is quite characteristic of the masses mentioned.

The drusy cavities are usually lined by analcite and ægirine crystals, visible to the naked eye. The icositetrahedral planes of the former are distinct under a lens, although the colorless crystals seldom exceed 2 or 3 mm. in diameter. In the phonolite of Nipple Mountain analcite reaches its greatest observed development, in yellowish crystals, some of which are nearly half a centimeter in size.

In the phonolite of Cow Mountain, southeast of Trachyte Peak, there are in some places extremely narrow fissures, noticeable only on fresh fractured faces through the brilliant ægirine prisms lining them, while those in the rock mass are dull through the minute inclusions.

The occurrence of analcite.—It is probable that analcite occurs in all but the denser phonolites of the region, either in drusy cavities described or in irregular patches adjacent to the large nepheline crystals of the porphyritic phonolites. In a few cases there are narrow veins of analcite in fresh dense rock, with ægirine of pure substance and good crystal form embedded in it.

The facts that zeolitization with recognizable products is not pronounced in the phonolites, and that the analcite described is always associated with fresh, pure ægirine, and often with nepheline, lead to the conclusion that the analcite of these rocks belongs to the final period of consolidation, when the excluded water contents of the magma had been concentrated by a kind of differentiation, in spots or along certain planes, perhaps associated with other mineralizing agents.

The occurrence of analcite in these rocks is closely analogous with that described by Jos. Blumrich in certain Bohemian phonolites,[1] where the analcite of narrow drusy cavities and veinlets serves as a matrix for albite tablets, hainite, ægirine, nepheline, and nosean. Chabazite also appears in this case, and is slightly older than the analcite. Blumrich also regards the analcite and chabazite as primary, and compares the narrow druses and veinlets of the phonolite with the syenite-pegmatite veins of the elæolite-syenite masses of southern Norway, so exhaustively investigated and described by Brögger. He argues for a similarity in conditions of origin, and there are certainly many striking similarities between the almost

[1] Die Phonolithe des Friedländer Bezirkes in Nordböhmen, Tschermak's Min. und pet. Mitth., 1893, Vol. XIII, pp. 465-495.

microscopic veins of these and other rocks and the large veins of coarsely crystalized minerals known not only in nepheline-bearing rocks.

The peculiar rock of Bull Cliff.—The rock forming the summit of Bull Cliff, and represented upon the map as a broad dike extending to the south, exhibits certain peculiarities not seen in any other mass of the region, but owing to insufficient observations these peculiarities are at present not understood.

In the cliff proper the rock is a dark-gray spotted mass, without the usual fissile structure of the phonolites, and is characterized instead by a very uneven fracture. The spots are slightly darker in color than the rest of the rock, and represent rounded areas of hazelnut size, without sharp boundaries, and the fractures tend to pass around rather than through these darker parts. There is a rude columnar structure in the face of the cliff, the columns being a foot or more in diameter, and standing nearly vertical. Field observations seemed to show that this material graded insensibly into normal phonolite on the eastern contact and southward, and it was not suspected that any great difference in mineral or chemical composition could be present between the different parts. But both microscopical and chemical examinations show that the cliff rock is widely different from any other of the region. It is rich in lime and magnesia, and contains much augite and plagioclase, with a high amount of alkali feldspar. On the whole, the composition approaches that of the rock from Brazil described by Rosenbusch and Hunter, to which they gave the name monchiquite.[1]

As it is hoped that opportunity may soon be found to reexamine the locality and determine the true connection between this rock and the adjacent phonolite, no further description of the Bull Cliff rock will be given here. It is not distinguished from phonolite on the map.

INCLUSIONS IN PHONOLITE.

Nepheline-syenite.—In loose fragments of phonolite from Nipple Mountain, Big Bull Mountain, and various other places, small angular pieces of a grayish granular rock were observed as inclusions. Only single ones were found in any one locality. The fragments were small, from 1 to 3 inches in diameter, with sharp contacts against the phonolite. All of these inclusions prove to be nepheline-syenite, similar to the large body at the southern base of Bull Hill, but somewhat finer grained.

From the wide distribution of these fragments they are to be regarded as detached pieces from some deep-seated nepheline-syenite body in the volcanic conduit, which has been traversed by later phonolitic magmas of the same general period.

Olivine.—The phonolite of the dike in tuff on the southwestern ridge of Rhyolite Mountain contains numerous dark, dull-appearing particles,

[1] Tschermak's Min. und pet. Mitth., Vol. XI, 1890, p. 445.

up to 3 or 4 mm. in size, which prove to be olivine grains of quite fresh substance within but surrounded by a thin reaction border consisting of three zones. The inner zone is black, and to a great degree opaque, made up apparently of magnetite dust with minute prisms lying at right angles to the olivine surface, and so obscured by the magnetite dust that their character can not be determined, aside from the fact that they all seem to extinguish parallel to the prismatic axis.

The middle zone consists of a colorless mineral in an irregular aggregate of very minute flakes, with strong polarization, and that this substance is muscovite seems indicated by the gradation into the outer zone, which is a coarser aggregate of light-brown biotite flakes, of strong absorption. Ægirine needles of the adjoining phonolite are especially collected next to this biotite zone.

CHEMICAL COMPOSITION.

Types analyzed.—Four somewhat different varieties of the phonolites of this district have been analyzed by Dr. W. F. Hillebrand in the chemical laboratory of the Survey, with the results given under I, II, III, and IV of the accompanying table. With these are compared: V, the analysis by Mr. L. G. Eakins, of the erratic phonolite bowlder described by the writer some years ago;[1] VI, the analysis of phonolite from the Devil's Tower, near the Black Hills, published by Mr. L. V. Pirsson;[2] VII, an analysis by vom Rath of a typical phonolite from the Lausche, near Zittau, Saxony.[3]

The essential characteristics of the rocks analyzed may be summed up as follows:

I. A grayish rock, porphyritic from the abundance of red nepheline crystals, ± 1 mm. in diameter, scattered uniformly through the mass. These nepheline crystals lie in a feldspathic microlitic ground-mass peppered with ægirine needles. A few apparent nosean crystals are present. Analcite in irregular particles is associated with large nepheline crystals and pure ægirine needles. A few of the ægirines have a core of ægirine-augite.

II. From hill 1 mile south of Straub Mountain. Collection No. 2252. The rock is very dense, mottled light and dark greenish-gray, the lighter parts being frequently about small, irregular druses, in which are minute ægirine needles and glassy analcite crystals. A few small tabular phenocrysts of anorthoclase are present. The ground-mass consists chiefly of sanidine microlites and abundant clear nepheline crystals. Ægirine is developed in ragged prismatic grains which sometimes have a core of ægirine-augite. There are a few small phenocrysts of nosean. Sodalite, which the analysis would indicate to be very abundant, is not easy distinguishable, as its tiny crystals contain but few of the customary inclusions.

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[1] Note on phonolite from Colorado, Proc. Colo. Sci. Soc., Vol. II, 1887, p. 167.

[2] Phonolitic rocks from the Black Hills, Am. Jour. Sci. (3), Vol. XLVII, 1894, p. 341.

[3] Quoted by Zirkel, Lehrbuch der Petrographie, 2nd ed., p. 446.

III. From Mitre Peak, a phonolitic cone south-southwest of Grouse Mountain. Collection No. 2234. This rock is dense greenish-gray, with a few nosean crystals (1 to 3 mm.) and none of feldspar. Microscopically the rock has marked trachytic structure from the abundance of sanidine microlites, and is rich in nepheline crystals of maximum size of 0.08 mm., which are very distinct and pure, often embedded in skeleton crystals of ægirine. Sodalite is present in minute crystals averaging .025 mm. in diameter. Magnetite is wanting. Colorless particles (låvenite ?) of irregular shape occur between the other constituents.

IV. From a narrow dike in granite northeast of Big Bull Mountain. Collection No. 2260. A reddish-gray fissile rock of pronounced trachytic habit. It has numerous glassy tabular phenocrysts of anorthoclase, a few macroscopic flakes of biotite, and minute prisms of ægirine-augite. Magnetite grains can be detected with a hand lens, but nosean is not distinguishable. Under the microscope the reddish color is seen to be due to particles of limonite, which give the mass the familiar dusty appearance, and obscure nepheline and sodalite, which the analysis indicates must be present in nearly the usual amount. The development of feldspar in scales, rather than in prismatic microlites, also favors the concealment of nepheline and sodalite. The larger pyroxene prisms are ægirine-augite, while ægirine appears in small irregular particles between the feldspar scales. Except for the character of the pyroxenes, there is little in the appearance of this rock to suggest that it is not a trachyte, and it was selected for analysis as a representative of the extreme in this direction.

Analyses of phonolite from Cripple Creek district and elsewhere.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	58.64	58.78	58.98	59.00	60.02	61.08	59.17
ZrO_2	.09	.17	.20	.20	Undet.	.....	.....
TiO_2	.20	.29	.24	.29	Undet.	.18	.....
Al_2O_3	19.62	20.03	20.54	20.07	20.98	18.71	19.74
Fe_2O_3	2.17	1.87	1.65	1.58	2.21	1.91	3.39
FeO	.42	.49	.48	.65	.51	.63	.....
MnO	.20	.15	.26	.12	Trace.	Trace	.....
CaO	1.24	.83	.67	1.05	1.18	1.58	.92
SrO	Trace.	None.	None.	None.	Undet.	.....	.....
BaO	Trace.	None.	None.	Trace.	Undet.	.05	.....
MgO	.37	.16	.11	.10	Trace.	.08	.15
K_2O	5.26	5.50	5.31	5.63	5.72	4.63	6.45
Na_2O	8.39	9.36	9.95	8.34	8.83	8.68	8.88
Li_2O	Trace.	Trace.	Trace.	Trace.	.....	.....	.....
H_2O (*a*)	.34	.31	.19	.24	*b* .70	*b* 2.21	*b* 1.18
H_2O (*c*)	2.40	1.57	.97	2.03	.....	.....	.....
P_2O_5	0.03	.03	.04	.05	Trace.	.....	.....
SO_3	Trace.	.12	.20	.07	None.	Trace.	.....
Cl	.14	.58	.28	.24	Trace.	.12	.....
CO_2	.23	.....	.....	.26	.....	.....	.....
	99.74	100.24	100.07	99.92	100.15	99.86	99.88
Sp. gr.	2.52	.....	.....	.....	2.57	2.58	2.56

a H_2O below 110° C. *b* Includes all H_2O. *c* H_2O above 110° C.

Discussion of analyses.—In respect to silica, alumina, iron oxides, lime, magnesia, and the alkalies, these analyses are typical of phonolites of trachytic habit, rich in nepheline. The contents in SO_3 and Cl prove sodalite to be more abundant than nosean, which would hardly be suspected without chemical analysis, on account of the minute size of the sodalite crystals and the difficulty of detecting them when not rich in inclusions. The low percentage of lime makes the identification of larger isometric crystals as nosean reasonable.

The development of ægirine-augite with a very small increase in the amount of lime, in I and IV, is noteworthy. As already pointed out, the amount of zirconia found, taken in connection with the absence or great rarity of zircon crystals, seems to confirm the identification of låvenite, or at least to show that some rare mineral of similar composition is present. The small percentage of phosphoric acid becomes interesting by contrast with the large amount in the andesites and in the nepheline-basalt. The titanic acid may belong in part to some rare silico-titanate not identified, or to pyroxene.

In the phonolite of Analysis V, Mr. Eakins found 25.39 per cent soluble in hydrochloric acid, and this soluble portion, calculated to 100, had the composition: SiO_2 44.66, Al_2O_3 31.59, Fe_2O_3 0.95, CaO 2.25, Na_2O 18.42, K_2O 2.13=100. This corresponds so nearly to the composition of nepheline that it is necessary to assume that the greater part of this soluble portion belonged to that mineral. In the rock of Analysis I Dr. Hillebrand found 35.46 per cent soluble in cold dilute hydrochloric acid, 4.55 per cent being Na_2O, and 0.49 per cent K_2O. Of the phonolite from Mount Pisgah, which is exceptionally rich in very distinct nepheline crystals, Mr. H. N. Stokes found 40.15 per cent soluble in cold dilute hydrochloric acid. The phonolite of Analysis VII contains, according to vom Rath, 36.22 per cent of substance soluble in hydrochloric acid.

Comparison with other phonolites.—The phonolites of the Cripple Creek volcano evidently possess a marked similarity in composition with the phonolite described by Pirsson from the Devil's Tower, though undoubtedly containing more nepheline, as the percentages of silica, alumina, and soda show. The presence of sodalite in both rocks especially marks them as intimately related and contrasting with otherwise similar occurrences.

In general the Colorado rocks are very nearly allied to numerous occurrences of Saxony and Bohemia in which nosean is abundant. But the prominence of sodalite is a feature which thus far particularly distinguishes these phonolites. It appears not impossible, however, that sodalite in very minute ground-mass particles has been overlooked or confounded with nosean in phonolites of various localities. Zirkel cites several instances of European phonolites in which sodalite has been identified or suspected from the presence of chlorine.

Where associated with large nosean crystals, as in the rocks here described, chemical tests must be relied upon.

A comparison of these and similar phonolites with the members of the phonolitic group which have been called *tinguaite* by Rosenbusch, Brögger, and others, brings up the broad question of what is desirable and feasible in defining and naming the several varieties of igneous rocks within a given group. General discussion of these relationships will, however, be deferred until other phonolitic rocks in the writer's possession have been examined. These were found in New Mexico by Mr. S. P. Baldwin, and will be described in a bulletin of the United States Geological Survey. The recent publication by Brögger[1] on a very interesting series of rocks from the Christiania region in Norway, which are rich in silica and alkalis, advocates the naming of very minute subdivisions of rock groups upon criteria which seem to the writer applicable only to the rocks of certain petrographical provinces.

In general the Colorado phonolites differ from the tinguaites of Brögger in the prominence of the trachytic structure, the smaller amount of iron-bearing minerals, and the presence of nosean and sodalite.

TRACHYTIC PHONOLITE.

Structure and mineralogical composition.—The rocks included in this group are massive, dark-green or almost black in color, and possess a distinct porphyritic structure. They are holocrystalline, but vary in grain and in the ratio of ground-mass to phenocrysts. In the coarse-grained phases there are many glassy feldspar crystals of rather thick, tabular form, varying from 2 or 3 mm. to more than 1 cm. in size, with smaller and less numerous pyroxenes, and a few hornblende prisms. Occasionally the rock seems almost macrocrystalline, but there is, even in these cases, a ground-mass of feldspar microlites, with augite and magnetite in very subordinate amount, winding about or between the phenocrysts, producing a fluidal structure. Usually phenocrysts and ground-mass are almost evenly balanced, and the latter has a dull-green color, from the uniformly distributed augite grains.

The minerals of the rock under discussion are the same as those found in the normal phonolites, with some differences of development to be pointed out. The feldspar phenocrysts are chiefly of sanidine or soda-orthoclase, with no distinct polysynthetic twinning, but there is always a considerable number of crystals possessing an extremely delicate lamellar albite twinning, and these seem to be albite. About the center of substance of this character there is commonly an irregular zone of sanidine or anorthoclase. The microlitic feldspars of the ground-mass seem to be sanidine or soda-orthoclase.

Next to the feldspars in importance is augite, occurring in small prisms as phenocrysts and in minute microlites in the ground-mass.

[1] Die Gesteine der Grorudit-Tinguait Serie. 8°, pp. 206. Christiania, 1894.

It is very pale green in color, and only occasionally shows a decided admixture of the ægirine molecule by marked pleochroism, yet the outer zone is almost always perceptibly darker green, and in a few cases is strongly so. Ægirine is developed very scantily as an irregular outer zone about a few augite prisms in certain rocks.

A dark-brown hornblende is present in most of the specimens. It has always suffered very strong magmatic resorption, with the common product of magnetite and augite, but this secondary rim is here unusually coarse grained, and the augite is often in large part oriented as one individual with the crystal axes $\bar{\mathfrak{b}}$ and $\dot{\mathfrak{c}}$ parallel to those of the hornblende. The hornblende is very dark brown, with the extinction angle $\mathfrak{c} : \dot{\mathfrak{c}}$ at least 30°, and the absorption formula $\mathfrak{b} > \mathfrak{c} > \mathfrak{a}$. This seems to bring it within the definition of Brögger's *katoforite*, which occurs in very similar rocks of the Christiania region.[1]

Nosean and sodalite appear to be almost as abundant in this rock as in the other phonolites, but they can not be so well distinguished in their development here. The phenocrysts corresponding to nosean of the phonolite are usually numerous, and are sometimes very characteristically marked by the dark lines of inclusions or by a dark outer zone. When included in feldspar or augite the crystals are sometimes pale-blue in color and without a trace of dark border or inclusions. Those only partially embedded in feldspar show the secondary darkening in the portion exposed.

Sodalite can seldom be distinguished from nosean, either because of a gradation in size between large and small grains of similar appearance or from a total absence of identifiable microscopic particles referable to this group, yet chemical tests show chlorine in quantities corresponding to several per cent of sodalite in some rocks where it can not be identified.

The importance of nepheline in these rocks is very difficult to estimate. It has been distinguished in a few thin sections in its usual stout prismatic crystals, but never in any abundance. In the rock of which a quantitative analysis is presented below no nepheline is determinable, although the analysis agrees closely with the analyses of the typical phonolites. It is probable that the nepheline is present in xenomorphic grains as a cement to feldspar microlites, and is not distinguishable from feldspar.

Magnetite occurs in scattered phenocrystic grains, often included in augite, and in very minute particles in the ground-mass, corresponding throughout to the development of augite.

Of the accessory minerals, titanite and apatite are present in small crystals to be included among the phenocrysts. The few apatite crystals are short, thick prisms, usually carrying many axial inclusions. Låvenite is distinctly present in one rock, and may occur in several others.

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[1] Die Gesteine der Grorudit-Tinguait Serie, p. 37.

Chemical composition.—The dark, fresh rock from the dike on the west slope of Bull Cliff was analyzed by Dr. Hillebrand, with the following result:

Analysis of rock from dike on west slope of Bull Cliff, Colorado.

	Per cent.
SiO_2	59.38
ZrO_2	.10
TiO_2	.58
Al_2O_3	19.47
Fe_2O_3	1.60
FeO	1.19
MnO	.15
CaO	1.96
SrO	.03
BaO	.13
MgO	.36
K_2O	5.83
Na_2O	7.80
Li_2O	Trace.
H_2O (*a*)	.11
H_2O (*b*)	.69
P_2O_5	.08
SO_3	.37
Cl	.22
	100.05

a Below 110° C. *b* Above 110° C.

The close agreement of this analysis with the analyses of the more typical phonolites is striking, the most marked difference being in the increased percentage of lime here shown. This, apparently, has the effect of producing augite in place of ægirine-augite, even with an increase in iron. This latter increase is, however, in the protoxide, and is connected with the development of magnetite to a degree not seen in any of the rocks classed as normal phonolite. Corresponding to the prominence of nosean, there is a larger amount of sulphuric acid than in the phonolites proper.

It would seem probable from a comparison of the analyses that there must be nearly as much nepheline in this rock as in the other phonolites, but it could not be detected microscopically in any great abundance, and the solubility test made by Mr. H. N. Stokes on the rock of the analysis indicates a considerably decreased percentage of that mineral in the rock variety under discussion. Mr. Stokes found 20.32 per cent soluble in cold dilute hydrochloric acid, and in another rock of this type he found 18.96 per cent soluble. This latter rock contained 0.24 per cent SO_3 and 0.12 per cent Cl.

The above results indicate a considerably less amount of nepheline than in the phonolites proper, and a larger amount of nosean. The rock is intermediate between trachyte and phonolite, and for purposes of local distinction has been designated trachytic phonolite.

NEPHELINE-SYENITE.

Structure and mineralogical composition.—A granular rock corresponding nearly to phonolite in composition occurs at the southern base of Bull Hill. When in fresh condition it is a medium fine-grained

rock having a predominant pearl-gray mass of feldspar, nepheline, and a regular mineral (sodalite or nosean), with abundant dark blades and irregular grains of pyroxene and hornblende. Yellow sphene is abundantly sprinkled through the mass in macroscopic crystals.

The rock resembles a hornblende-diorite at first sight, but close examination shows augite to predominate over hornblende, and the feldspathoid portion, though evidently granular, is not so easily resolvable into clearly defined grains as is usual in granitic or dioritic rocks. The microscope shows this indistinctness to be due to a very intimate interlocking of the irregular grains of alkali feldspar and nepheline. But few feldspar grains exhibit any polysynthetic twinning, and then the indication is of anorthoclase or microperthite rather than of the albite-anorthite series. The greater part of the feldspar is not easily distinguished from nepheline, as the latter occurs also in xenomorphic grains and both are clouded by secondary fluid inclusions and dusty particles. On further decomposition, however, the nepheline passes into a probable zeolitic mass, showing strong aggregate polarization, as does the isometric constituent, and in such cases the relative abundance of the different minerals can be estimated.

The isometric mineral is of a pale-green color when included in feldspar, which has preserved it. In other grains its character is obscured by fluid inclusions and the secondary substances developing. None of the grains have regular crystal form, and the regular or zonal arrangement of interpositions characterizing the nosean phenocrysts of the phonolites is entirely wanting. The resemblance with sodalite is stronger than with nosean, and the chemical analysis confirms this impression as correct.

Augite is much more abundant than hornblende. Biotite is variably developed, but is always subordinate to hornblende. The augite is of very pale-green color, and is developed either in tabular prisms parallel to the orthopinacoid or in irregular grains. A grass-green color indicating admixture of the ægirine molecule is occasionally strong. The hornblende has a dark olive-green color, and occurs chiefly as an irregular oriented zone about the augite. It thus possesses the usual features of the mineral as elsewhere observed in nepheline-syenites, and contrasts markedly with the hornblende of the phonolitic trachyte, which was dark-brown in color and older than augite, as shown by the resorption phenomena. This green hornblende has also a high extinction angle, 30° being the maximum observed. Biotite is often intergrown with hornblende or augite, and also appears in small isolated leaves. It has a dark reddish-brown color and very strong absorption.

Titanite and apatite are unusually abundant accessory constituents and more prominent than magnetite. No other minerals of primary character were observed.

Chemical composition.—The freshest rock collected, from near the Longfellow mine, gave Dr. Hillebrand the following result:

Analysis of rock from near Longfellow mine, Cripple Creek district, Colorado.

	Per cent.
SiO_2	54.34
ZrO_2	.07
TiO_2	1.09
Al_2O_3	19.23
Fe_2O_3	3.19
FeO	2.11
MnO	.08
CaO	4.53
SrO	.16
BaO	.24
MgO	1.28
K_2O	5.14
Na_2O	6.38
Li_2O	Trace.
H_2O (*a*)	.14
H_2O (*b*)	1.17
P_2O_5	.27
SO_3	.07
Cl	.28
	99.77
Sp. gr	2.68

a Below 110° C. *b* Above 110° C.

A comparison of this analysis with the analyses of the rocks previously described is interesting as showing that a rock may contain much larger amounts of lime, magnesia, and iron oxides than did the phonolites and still remain an alkali-feldspar rock with abundant nepheline. This is possible through the decrease in silica with continued high percentages of alumina and alkalies and the entrance of iron, lime, and magnesia almost exclusively into the dark silicates, augite, hornblende, and biotite. The close relationship with the phonolitic magmas is further emphasized by the contents in chlorine and sulphuric acid. The latter indicates the presence of nosean, although it was not distinguished in the thin sections.

In several minor features this nepheline-syenite is similar to the more basic rocks of the volcano, viz, in the increased amounts of titanic acid, phosphoric acid, and the earths strontia and baryta.

AUGITE-SYENITE-PORPHYRY.

Structure and mineralogical composition.—In the upper part of Anaconda Ridge, south of Gold Hill, is a mass of a rock not found elsewhere. It is a somewhat mottled ashen-gray rock, of subordinate porphyritic structure owing to the small size of the feldspar and augite phenocrysts. The principal part of the rock is its coarse-grained granular feldspathic ground-mass, through which are sparsely scattered minute grains of green augite. In the freshest specimen found the feldspar is much obscured by secondary dusty interpositions, but it is in very large degree orthoclase, with a fine lamellar albitic twinning in only a few of the small phenocrysts, and then often surrounded by a zone of simple structure. No indications of nepheline or sodalite could be detected, although the feldspathic constituent is almost entirely alkali feldspar, as in the nepheline-syenite of Bull Hill.

The augite of this rock is pale-green, and does not show signs of the ægirine molecule. It occurs in small, ill-developed prismatic phenocrysts, in ground-mass particles as mentioned, and with magnetite as a product of the resorption of yellowish-brown hornblende, in a few individuals. Biotite is very light brown in color, and its absorption, like that of the hornblende remnants, is less than in other rocks of the alkaline series.

Titanite, apatite, and magnetite are well-developed accessory constituents, much more abundant than in any of the rocks thus far described.

The chemical relationship of this rock is clearly with the dominant strongly alkaline series of the volcano, but another relationship is also strong, as is proved by a fine granular rock shown on the dump of a prospect shaft on the western border of the mass. This rock has much pale-green augite and brown biotite, with plagioclase and orthoclase in nearly equal amounts. The former feldspar occurs in small, rudely automorphic crystals, with orthoclase in irregular grains between or in oriented enlargement of the plagioclase individuals. The structure is that of many augite-mica-diorites known to the writer, and the rock is intermediate between syenite and diorite. The plagioclase appears to be oligoclase with a few very finely lamellar twinned crystals of albite. It is supposed that this diorite is a facies of the larger mass, as it was not observed elsewhere, but the relation of the two rocks was not shown in the shaft, and there were no outcrops near this place.

ANDESITE.

The first massive rock of the Cripple Creek volcano, and that which predominates in the breccias and tuffs, is an andesite of certain well-marked characteristics. In the later period of the volcano somewhat different andesites were erupted as small flows or injected as dikes into the mountain mass. Many of the dikes are so much decomposed that the rocks can scarcely be identified, and few are so well preserved that their constitution and structure can be satisfactorily determined. The most important and best preserved varieties will be briefly described.

THE FIRST MASSIVE ANDESITE.

The rock of the freshest remnants of this type is dark, holocrystalline, porphyritic in structure, containing many small tabular phenocrysts of feldspar 1 to 3 mm. in size, and a few larger ones, augite in a development similar to that of the feldspars, and in some cases biotite in small, brown, glistening crystals, usually much fresher than the augite.

The microscope further shows aggregates of augite needles and magnetite grains, with outlines demonstrating that hornblende was once present in the magma, but no trace of hornblende substance has been seen, and the outlines are often wholly irregular. The comparative

freshness of biotite, when present, does not allow the assumption that much of this apparent secondary development of augite and magnetite can have been derived from a mica.

The phenocrysts of feldspar are mainly plagioclase, and belong, as far as can be determined, in the oligoclase or andesine groups. Probably all are plagioclase, except, perhaps, those in the rocks with subordinate ground-masses, where it seems possible that there may be some crystals of orthoclase. These rocks are, as it happens, so much decomposed that many crystals can not be determined. In form the plagioclases have the usual habit of phenocrysts in andesites, with zonal structure and numerous glass inclusions. If the ground-mass is prominent the crystals are most sharp and regular in form. If the ground-mass is scanty and coarsely crystalline the phenocrysts often have a more or less irregular zone of oriented orthoclase about them.

The most remarkable constituent of the rock is apatite, which is developed in macroscopic crystals showing prism, pyramid, and basal plane, and nearly as large as the augite. Prisms 2 to 4 mm. in length are not uncommon, and a thickness of 3 mm. has been observed. These apatite crystals are usually smoky-brown in color, and where the conchoidal fracture is seen they greatly resemble smoky quartz. Where the rock is somewhat dull through alteration the fresh apatite crystals are the most prominent constituent and become of diagnostic value. The microscope shows the color to be due to an unusual abundance of the well-known dark axial inclusions. The crystals are seldom corroded. A dozen or more can sometimes be identified with a hand lens in a thin hand specimen 3 by 4 inches in size. Dr. Hillebrand found 0.73 per cent phosphoric acid in one of these andesites.

The ground-mass varies much in abundance and development, being microlitic in some cases and coarsely granular in others. Wherever the ground-mass is fresh and coarse-grained, orthoclase seems to predominate over plagioclase, but calcite, chlorite, and the usual dusty interpositions often obscure the mass. Augite and magnetite are constant constituents of the ground-mass in the usual forms. No evidence of a former glassy base has been seen in any of the sections examined.

This early andesite is plainly very near in composition to that which was the first massive rock of the Rosita volcano in Custer County,[1] 40 miles south of Cripple Creek. In the latter rock small phenocrysts of pink orthoclase are usually developed in subordinate amount, while augite, hornblende, and biotite are often present together.

No specimens of this andesite were obtained which were sufficiently fresh to warrant chemical analysis. It is plain that the magma producing this rock was richer in alkalies, and especially in potash, than is usual for andesites of generally similar constitution.

[1] Geology of the Rosita Hills, Custer County, Colo., by Whitman Cross, Proc. Colo. Sci. Soc., Vol. III, 1890, pp. 271-279.

DIKE ANDESITES.

Within the area of volcanic breccia are a considerable number of dikes of rocks which do not possess the schistose structure of the phonolites, but are in most cases so decomposed that their original character can no longer be clearly made out. The majority of these dikes appear to be andesites, in cases where the dark silicates and the feldspar phenocrysts can be determined, but as augite and hornblende are usually completely decomposed, and even the prism outlines destroyed, and the feldspars are often muscovitized, it is doubtful whether some of these rocks are not phonolites of the trachytic type. The ground-masses are almost always microlitic, but so clouded, or of so fine grain, that the character of the microlites can not be ascertained. As all but the most basic rocks of this center are rich in alkalies, it is to be inferred that alkali feldspars predominate in the ground-masses of these dike rocks. As a rule the structure is similar to that of the trachytic phonolite.

Two varieties of these dike andesites are sufficiently well preserved to permit recognition of their characteristics. One of these seems to be restricted to Battle Mountain, where it occurs in several small bodies in the breccia. It is an *augite-mica-andesite* in which the augite is now almost wholly replaced by an aggregate of decomposition products, and the dull straw-yellow or brown matter filling the prism areas contrasts markedly with the fresh flakes of brown biotite. The plagioclase phenocrysts are oligoclase or andesine, and are commonly surrounded by a rim of monoclinic feldspar. The ground-mass is microlitic, containing augite prisms and magnetite dust in the fresher specimens.

The rock in question is similar to the earlier massive andesite. but is richer in biotite, and probably has a higher percentage of alkali. It has phenocrysts of titanite, magnetite, and apatite, the latter reaching a remarkable development in some cases. In one hand specimen fifty crystals of apatite can be distinguished with the aid of a common hand lens, one crystal reaching a length of 7 mm. and a thickness of 3 mm. The prisms are terminated by pyramid and basal plane, and are of pearl-gray color, the inclusions being much smaller than in the apatite of the massive andesite, where they usually produce a smoky color. In this rock Dr. Hillebrand found 0.67 per cent of phosphoric acid.

In the Anaconda tunnel two dikes are met of a dark, fresh andesite containing augite, biotite, brown hornblende, and numerous plagioclase phenocrysts, and a feldspathic microlitic ground-mass with augite and magnetite. The plagioclase crystals are oligoclase or andesine, and do not show the zonal structure so common in surface andesites. The rock is apparently an andesite richer in alkali than usual. Several other dikes of Anaconda Ridge seem to belong to this type, though very much decomposed.

BASIC DIKE ROCKS.

The latest eruptions of the volcano are represented by a number of narrow dikes of basic rocks of several types. They are as a rule inconspicuous on the surface, and most of them are extremely decomposed, so that exact identification is impossible, but in a number of places comparatively fresh material has been exposed by mine or prospect workings, and the characteristics of two widely different types have thereby been well established.

PLAGIOCLASE-BASALT.

One of the more common dike rocks is a dark-gray or black basalt having many small crystals of augite and olivine, with a few of plagioclase-feldspar, and a crystalline ground-mass of plagioclase, orthoclase, biotite, magnetite, and the usual accessory apatite needles. While augite and olivine are almost wholly developed in distinct crystals, the gradation in size of the plagioclase tablets from those 1 to 2 mm. in length down to the microlites of the ground-mass somewhat obscures the distinctness of the porphyritic structure. Biotite occurs in many minute, deep reddish-brown flakes which are rarely automorphic.

The most noteworthy characteristic of these basalts is the presence of orthoclase, or at least a monoclinic feldspar, both in subordinate oriented zones about the plagioclase crystals, and also as the principal interstitial or residual substance between the other constituents. The oriented zones surrounding plagioclase are variable in breadth and always interlock irregularly with the ground-mass grains. It is possible that some nepheline is present in the ground-mass of this rock, for much of the assumed orthoclase substance is clouded by secondary interpositions. But the rock is very similar to the orthoclase-bearing basalt of Table Mountain, at Golden, Colo., and no direct evidence of nepheline was obtained. It seems not unnatural that orthoclase should be developed here, for the rock is evidently one of the basic extremes of differentiation in a center specially characterized by the high alkali contents of its various magmas.

Feldspar-basalt of this type was found in nearly fresh condition in a shallow prospect hole about 100 feet southwest of the Dolly Varden shaft house, and in a shaft on the Wilson claim north of Altman. The latter represents a dike running about northeast, and is probably the same as that exposed in the southern drifts of the Buena Vista mine. Other dikes of this type no doubt occur.

NEPHELINE-BASALT.

The dark dike of the Elkton and Raven mines, on Raven Hill, and that of the Black Diamond, on Battle Mountain, represent another type of basaltic rock, very rich in olivine, augite, and magnetite, and with a very subordinate colorless residual base which polarizes very

faintly. A few minute feldspar microlites are present, but the greater part of the colorless residual matter would seem to be nepheline.

In these rocks olivine is commonly developed in more distinct crystals than augite. It is especially so in the rock of the Black Diamond, where it is very fresh in the specimen studied microscopically. Biotite is usually present in small, irregular flakes through the ground-mass.

The rock from the Appie Ellen shaft, south of the Elkton, representing the freshest material obtainable from this dike, was analyzed by Dr. Hillebrand, with the following result:

Analysis of rock from the Appie Ellen shaft, Cripple Creek district, Colorado.

	Per cent.
SiO_2	35.03
ZrO_2	None.
TiO_2	2.20
Al_2O_3	9.80
Fe_2O_3 (*a*)	5.55
FeS_2	.38
FeO (*a*)	4.98
MnO	.06
CaO	15.09
SrO	.17
BaO	.14
MgO	9.78
K_2O	2.16
Na_2O	2.04
Li_2O	Trace.
H_2C (*b*)	.41
H_2O (*c*)	2.05
P_2O_5	1.99
CO_2	7.83
Cl	Trace.
	99.66
Sp. gr. at 23° C.	2.99

a Perhaps slightly incorrect from presence of FeS_2.
b Below 110° C. *c* Above 110° C.

From the contents in carbonic acid and water, as well as from microscopical study, it is clear that the rock is much decomposed, but the analysis serves to confirm the general determination as a probable nepheline-bearing rock. This is further indicated by the fact that 43.35 per cent of the rock is soluble in cold dilute hydrochloric acid, and that the soluble portion carries nearly all of the soda (1.71 per cent Na_2O, 0.22 per cent K_2O). As far as can be determined from the much decomposed material collected from the dikes of the Sheriff, Moose, Kentucky Belle, Ben Harrison, Trail, Agnes, and Anna Lee mines, they are probably of this basaltic type.

TUFF AND BRECCIA.

The fragmental rocks which occupy the greater part of the volcanic area may all be embraced under the terms tuff and breccia. By the former is understood a rock made up of small particles corresponding in size to the grains of sand or gravel and angular in shape. This tuff is the product of explosive volcanic eruptions, and consists chiefly

of finely comminuted igneous rocks, with a variable amount of the granite through which the volcano has burst. By an admixture of larger angular fragments there is a transition to breccia, which is chiefly composed of pieces of some considerable size, with a very subordinate gravelly matrix.

Texture.—The greater part of the fragmental material accumulated in and about the Cripple Creek volcano is tuff of rather coarse texture, or tuff with some few larger fragments embedded in it, a phase which may be called tuff-breccia. Occasionally small masses are found which are like fine, even-grained sandstones, and these may be either massive or rudely bedded. A considerable part of the material is breccia, but this never becomes very coarse, the fragments rarely exceeding 3 or 4 inches in diameter. The irregular mixture of large and small fragments, usually called agglomerate, and found in or about the vents of large volcanoes, is lacking at Cripple Creek. Apparently the explosions were so violent or so often repeated that the ejected materials were reduced to very small dimensions. The tuff-breccia may be considered as an equivalent of such an agglomerate on a very small scale.

The materials of different textures are mingled in very complex manner throughout the area, and their distribution will be discussed in the next chapter.

Rock constituents.—The extreme decomposition to which the tuffs and breccias have been subject has often rendered identification of the materials composing them impossible, but in many localities the rock fragments are sufficiently fresh to allow conclusions in regard to the whole. Andesite is the principal element, together with phonolite in varying abundance locally, and débris of the granites and schists pierced by the volcanic vent.

The main andesitic type represented in the breccia is the augite-andesite with large apatite crystals, which has already been described. This forms the principal part of the tuffs and breccias surrounding the patches of massive andesite shown upon the map. Where comparatively little altered, the tuff made up of such andesitic débris is purplish or reddish-brown in color. Dark-colored tuff or breccia, in which the andesitic character of the fragments is distinct, may be seen on the southeastern slopes of Battle Mountain; in Bull Cliff, below the Victor mine; on the ridge of Raven Hill, leading down to Anaconda; at many points near the eastern and northern borders of the area outlined upon the map; and in Rhyolite Mountain.

Microscopical study of the breccias and tuffs shows that the structures of the constituent igneous fragments vary considerably, but that, excepting only the phonolites, all these structures are such as may be found in andesites. No doubt many different types are present, belonging to masses not now represented by massive bodies, and it may be that trachyte and other distinct rocks are elements of some of the finer-grained and much-decomposed tuffs and tuff-breccias, but no ground for assuming any such admixture has been found.

Phonolite fragments appear prominently in the tuff-breccias of portions of Raven Hill, Anaconda Ridge, and between Battle Mountain and Bull Cliff. While generally bleached, the schistose structure distinguishes many of those fragments, and here and there moderately fresh pieces are found. The distribution of this constituent of the breccia and its significance are discussed in the following chapter.

Granite and schist fragments of macroscopic size are met with at intervals all through the tuffs and breccias, but are most abundant in the portions near the borders of the volcanic district. The microscope, however, commonly reveals microcline or quartz in the finer-grained tuffs and in the matrix of the breccias. In certain places, as around Guyot Hill, the lowest or oldest tuffs found resting on granite are in large degree made up of granitic gravel.

Decomposition and induration.—The tuffs and breccias of the Cripple Creek volcano owe much of their present aspect to the processes of decomposition and induration to which they have been subject. Decomposition has primarily resulted in a total destruction of the dark silicates, augite, hornblende, or biotite, which may have been present in the rock fragments, and in the leaching out of the iron-bearing compound resulting from this decomposition, together with the original magnetite. Very often no trace of the dark silicates remains, and even their former outlines may have been so obliterated that no inferences as to their original character can be drawn. In other cases the outlines may indicate one or more of the species mentioned. The feldspars of these bleached rock fragments are as a rule altered to either kaolin or muscovite, and the phenocrysts much more completely than the microlites of the ground-masses. The large apatite crystals are often perfectly fresh long after other minerals have been much altered.

It may be assumed that the tuffs and breccias of this volcanic pile were for the most part loose and crumbling materials in the periods when this decomposition by gaseous or aqueous agents was accomplished, and that they were therefore easily permeable by circulating waters. Through the secondary products they have been indurated, and now often appear as nearly massive rocks. The induration was a silicification in some places, but more commonly comes from kaolin or muscovite, and hydrous iron oxide.

Thorough impregnation with pyrite in minute particles seems to have been a feature of much of the tuff and breccia, whether from early solfataric action or during the ore-deposition period is not clear. This pyrite has now been leached out over a large part of the district, leaving the rock porous and stained either yellow or reddish throughout, or with ocher lining the pores.

Where a tuff or fine-grained breccia is made up chiefly of small particles of a single rock type, such thorough alteration as has been described makes the rock nearly homogeneous and massive in appearance. In some cases only the microscope can show, by the varying

structures of different fragments, the clastic nature of the rock. The difficulty in distinguishing some of these purely fragmental aggregates is increased by the presence of breccias which are merely rock shattered in place.

The decomposition and disintegration of certain tuffs which have been heavily impregnated with iron and other oxides, and with fluorspar, has produced loose, crumbling material that should not be confounded with the purplish tuffs which have never been bleached and indurated. Such secondarily colored and disintegrated material has been exposed by the mines of Globe Hill especially.

RHYOLITE.

The rhyolite of Grouse Mountain is like that found in small remnants of surface flows over a large part of the region north and west of Cripple Creek for many miles. It seems to have no immediate connection with the Cripple Creek volcano.

The rock is light-gray or pinkish, with a few small quartz crystals and more numerous glassy sanidines and brown biotite flakes. These lie in a largely predominant, earthy-appearing ground-mass, which usually shows a flow structure more or less clearly.

Microscopical examination shows these rhyolites to be of very common structures. The ground-mass is micro- or cryptocrystalline, sometimes almost granular, but more commonly with axiolitic or microspherulitic structures indistinctly developed. In some cases trichites were once present, but are now largely decomposed. In many instances limonite flakes obscure the mass.

THE HIGH PARK LAKE-BEDS.

General character.—The only sedimentary formation of the district occurs about Straub and Grouse mountains. It is in itself an unimportant deposit, but by its relations to other rocks furnishes information of much interest as to the age of certain dynamic movements, and perhaps of the Cripple Creek volcano.

The formation is best seen on the slopes of Straub Mountain and of the ridge to the south. It is essentially an arkose grit, generally of rather loose texture, not well indurated. The angular grains composing it are chiefly quartz and feldspar, representing the granite of the region, with occasional larger fragments of granite. It is roughly bedded, and is of reddish color as a rule. By reason of its imperfectly indurated condition it seldom forms outcrops, and it is clearly seen only where exposed by prospect shafts, which are, however, quite numerous. The resemblance to the Upper Carboniferous arkose grits of the Fountain formation, the well-known "Red beds" of the neighboring foot-hill section, is very marked as seen in Straub Mountain.

The grits found in Grouse Mountain and the ridge leading southward to Little Pisgah Peak contain granite pebbles and some of hard,

blue, Algonkian quartzite, well worn, which were not observed in Straub Mountain. The beds rest upon rhyolite at certain points, as at the south base of Grouse Mountain, and there contain rhyolite fragments in abundance.

Little Pisgah Peak is a sharp cone of phonolite, less than 1 mile south of the southern boundary of the map. The flat ridge with grit and rhyolite extends from Grouse Mountain to Little Pisgah, and connects with a bench running around the peak on the north and west, on which grits may be found at several places, even out to the rampart points which project so boldly to the westward, and where rhyolite still underlies them.

Assignment to the High Park beds.—The correlation of these grits with the probable Miocene lake deposits of High Park rests on the following grounds, which are given in detail on account of the deductions based upon this reference. High Park is a depression of 10 or 12 square miles in extent, 5 miles north of west from Grouse Mountain, at a general elevation of 7,500 feet. Its smooth floor is partly due to volcanic tuff of the western volcanic area, but chiefly to a fine lake-bed deposit of yellowish sandstone, resting on a variable conglomerate made up of well-rounded pebbles of granite and many of a hard, dense, blue quartzite derived from Algonkian inclusions in granite of the vicinity. Only a few feet of the sandstones are preserved, and the conglomerate is but 30 or 40 feet in thickness at any point. Under this conglomerate there is commonly a thin sheet of rhyolite, from 30 to 50 feet in thickness, resting on the floor of granite. But locally this rhyolite has been eroded away and the conglomerate rests directly on granite, and then carries rhyolite fragments in it.

From the fact that the rhyolite is identical in character with many small remnants of flows which occur all over the region north of High Park, as far as Florissant, where they lie upon the tuffs of the Florissant lake basin, known to be of late Eocene (Oligocene) age from their fossil plants, insects, etc., it has been concluded that the High Park lake-beds must be of Miocene age.

About 2 miles southeast of High Park a thin sheet of rhyolite occurs capping the narrow "Red Ridge" at the extreme northern end of the Garden Park arm of sedimentary beds. This rhyolite rests unconformably on the Fountain Carboniferous grits, overlapping to the granite on the north, and has on top of it remnants of a conglomerate mainly of quartzite, like that of High Park. Although the Red Ridge rhyolite is 500 feet higher than that in High Park, the evidence seems to indicate that this is due to faulting and that the conglomerate of Red Ridge belongs to the High Park beds.

Red Ridge is but 3 miles west of the projecting ramparts of Little Pisgah Peak, though 1,000 feet below them. Seen from Red Ridge these granite projections seem like sharp points, but they have a flat top, with rhyolite and overlying grits upon them; the latter almost continuous to Grouse Mountain, as stated above.

To assume that the grits of Grouse Mountain belong to the deposits of the same lake as the beds of High Park and Red Ridge is to assume great faults in late Tertiary time. Between Little Pisgah Peak and Red Ridge runs a known fault whose displacement is nearly 1,000 feet at Wilson Creek, 2 miles southeast of the end of Red Ridge. The fault is one of the system bounding the sedimentary rocks of Garden Park, and no definite evidence as to their age is known, except that they are post-Cretaceous. The fact that the marked zones of sheeting from pressure which characterize the granite of the Cripple Creek district also traverse the volcanic rocks is evidence of an orographic movement of the late period to which it seems necessary to assign the fault in question.

Relation to phonolite.—Another bit of evidence which indicates both the equivalence of the grits of Grouse Mountain with the High Park beds and also the presence of the fault above alluded to some miles farther north, is contained in the relations of phonolite to rhyolite and the lake-beds in two separated localities. The grits of Grouse Mountain and the accompanying rhyolite are older than the large phonolite mass of the mountain, which has been laterally intruded nearly on the granite surface and has lifted up fragments of both formations, as shown by the map and described in detail in Chapter V. This relation of the phonolite serves to confirm the idea that the fault between Red Ridge and Little Pisgah continues several miles to the north, in that a very similar relation exists on the eastern side of High Park. There is at that point a hill on the west side of Oil Creek canyon which is chiefly made up of phonolite resting partly on the High Park beds, partly on rhyolite, and, on the eastern side of the hill, on granite. East of Oil Creek canyon rise rugged granite ridges 1,000 feet or more to the general plateau level of the Cripple Creek district. The fault in question would naturally lie east of Oil Creek and explain this similar association of these three formations at such different levels.

All these various data seem to point to the equivalence of the High Park and Grouse Mountain strata which are so similarly associated with rhyolite and phonolite.

ALLUVIUM.

The formations which are mapped as alluvium are for the most part the ordinary accumulations of soil and gravel found in the valley bottoms. As shown by the topographic map, this bottom-land is swampy in several places. In upper Beaver Park there was probably once a lake drained by the cutting of the canyon in granite at its southern extremity. The depth of the gravels at this point is not known.

MORAINE.

North of Trachyte Mountain is the end of a marked lateral moraine belonging to one of the Pikes Peak glaciers. A similar one lies east of

Trachyte Mountain, adjoining the map area. This has been largely rearranged. These two moraines are the most prominent ones noted in the survey of the Pikes Peak sheet.

GENERAL DISCUSSION.

THE MAGMAS.

By a review of the chemical composition of the rocks analyzed, and by inference from the mineralogical constitution of the other types, it is plain that as a whole the magmas of the Cripple Creek volcano were particularly characterized by the high percentage of alkalies they contained. Phonolite, trachytic phonolite, nepheline-syenite, and syenite-porphyry are all very rich in alkali feldspars and generally in soda-bearing pyroxenes. The andesites probably carry an unusually high amount of potash, resulting in the prominence of orthoclase in the ground-mass.

In this richness in alkali these magmas bear strong resemblance to those of the Rosita volcano, in Custer County, where trachyte and rhyolite are abundant, and the predominant andesitic rocks are all unusually rich in potash, so that orthoclase phenocrysts appear in several types.

Another characteristic of this vent is the presence of chlorine, fluorine, and sulphuric acid, represented in the sodalite, låvenite, and nosean of the phonolitic series. The first and last of these are decidedly rare in rocks of Colorado, but it is noteworthy that fluorine has been observed in acid alkaline magmas of several places in the State. It is known that fluorine accompanied the rhyolitic magmas of Silver Cliff, Nathrop, and Chalk Mountain, in the last two appearing in the topaz crystals of lithophysal cavities,[1] and in the first represented in both topaz and fluorspar. A special significance in this association of fluorine with alkaline magmas is indicated by the comparison to be made below between the volcanic and older rocks of this district.

THE ROCKS.

The proportions of alkali, alumina, and silica, together with the presence of chlorine and sulphuric acid in the more acid magmas, led to the great abundance of phonolite and allied rocks. And this fact is the most prominent and most distinctive characteristic of the volcano. It is rather remarkable that with several periods of eruption of these alkaline magmas there should have been such a constant composition as is shown by the rocks.

The occurrence of nepheline-syenite associated with phonolite in a Tertiary volcano affords proof that one of the most frequently cited examples of the essential differences between Tertiary and pre-Tertiary

[1] Cross, in Am. Jour. Sci. (3), Vol. XXVII, 1884, p. 94, and Vol. XXXI, 1886, p. 432.

igneous rocks has not the weight which has been given it. And it is interesting to observe in this connection that the nepheline of the granular rock has less the characters of the supposed older form of this mineral, elæolite, than have the phenocrysts of the porphyritic phonolite which has been described.

The development of the large apatite crystals so prominently in the andesites, and the appearance of låvenite and the associated blue amphibole in certain phonolites, form the most noteworthy mineralogical features of these rocks.

THE SUCCESSION OF MAGMAS.

While the succession of magmas of varying chemical composition in a small volcanic center must in general be considered as too local to have much significance in discussing from this side the broad questions concerning the origin of igneous rock groups, it is of interest that the sequence of this volcano agrees with the requirements of the generally accepted theories of the day. The first magmas were of intermediate chemical composition, yielding andesites; the principal eruptions of later times yielded strongly alkaline rocks, the phonolites, with quantitatively subordinate andesitic rocks; and the last eruptions were of quite basic character. These latter rocks are of very small amount compared with the phonolites, but they serve to prove that basic magmas contrasting strongly with the alkaline magmas of the earlier eruptions—*complementary magmas*, to use the very expressive term of Brögger—were present in the depths, even if not extruded in large amount.

RELATION BETWEEN ANCIENT AND RECENT ROCKS.

It has been commented upon, above, that as a whole the rocks of the Cripple Creek volcano, as far as known, are characterized by a high percentage of the alkalies, and that fluorine seems especially apt to be an associate of alkaline magmas; and the writer can not dismiss this subject without calling attention to certain other facts, although their significance must remain in great measure unknown.

The volcano has burst through granites, of types common for many miles on all sides. In the Spring Creek granite variety, and in others of the Pikes Peak area, Mr. Mathews has found a small amount of fluorite quite evenly disseminated through the rock. Observations are too few as yet to show in how far fluorite characterizes the granites of the region, but fluorine in various minerals enters into the constitution of many pegmatitic veins in the district about the peak proper. Fluorite and topaz appear in numerous crystals, associated with smoky quartz, microcline, albite, phenacite, zircon, and many other species, which have made the region of Pikes Peak famous the world over. Fluorine occurs more rarely in astrophyllite, and as a fluoride of rare earths in tysonite and bastnasite. A few years ago cryolite was identified by the writer in veins in a neighborhood where nearly all the above-named minerals

were known, and associated with several of them. Arfvedsonite (or riebeckite), astrophyllite, zircon, and fluorite are especial associates of the cryolite.

From the above it is clear that fluorine was a prominent element in the old granitic magmas as well as in the Cripple Creek volcano, and also that the magmas of the widely separated periods were both rich in alkalies. In how far there is any direct connection between these facts must remain a matter of speculation, in view of the fact that during all of Paleozoic and Mesozoic times there were no eruptions in this vicinity of which there is known evidence.

CHAPTER III.

THE CRIPPLE CREEK VOLCANO.

INTRODUCTORY.

Plan of chapter.—It is of prime importance to the student of Cripple Creek geology to appreciate fully that the igneous rocks of the mining district are actually in or close to the volcanic vent of which they are a product. In many places in Colorado one may find indications that a center of volcanic eruption is near at hand, but seldom are the evidences so distinct and conclusive, and the exact relations of the volcanic throat so clearly revealed by erosion, as in this district. Much that seems at first sight perplexing in the rock formations and in their relationships becomes natural enough when these facts are comprehended.

The general description of the district is planned to present the evidences of volcanic activity in a way that shall at the same time give some idea of the history of the district as it is now understood by the writer.

Evidences of true volcanic activity.—The concentration of varied phenomena of volcanic character about a very small center is one of the first and most striking features of the Cripple Creek district to force itself upon an observer. This is in a degree brought out by a glance at the accompanying geological map. The next most significant thing to claim attention is probably the fragmental character of much of the igneous material, which in its texture and components suggests only a volcanic origin. By examining the relation between this fragmental material and the massive granite and gneiss, direct evidence of the location of the throat of the old volcano is obtainable, and this is also in a measure shown by the map.

Entering into more detailed and technical examinations, it is found that in the relations of the various masses of different rocks, in their peculiar characteristics, and in the sequence in which they have appeared, there is strong confirmatory evidence of the typical volcanic character of the vent through which they have issued. One of the rock types, the phonolite, by its abundance and peculiarities of occurrence in relation to the center, not only emphasizes the position of the center, but stamps this volcano as differing markedly from any other known as yet in North America, for although the rock has been found in a few localities it has not been shown in those cases to be directly connected with true volcanic activity.

The sequence of events at this center embraces several periods of explosive outbursts alternating with more quiet eruptions. And it is probable that in the dying-out period of the volcano the usual cycle of activities was brought to a close in a very typical manner. There is every reason to assume that fumarole and solfataric emanations either succeeded several of the eruptions of molten magmas or were specially active in the earlier part of the closing period. Hot waters containing active chemical agents in solution must also be assumed as having performed a large part of the decomposition or alteration of the rocks about the center, and the ore deposition, which is certainly restricted in great degree to the region in which general alteration has taken place, was perhaps a distinct later phase of the action of the permeating solutions.

These different lines of evidence will now be considered in some detail.

THE FRAGMENTAL MATERIALS.

Mechanical constitution.—As shown by the geological map, the tuffs and breccias of the district occupy a much larger space than the massive igneous rocks, and the remnants of Mineral Hill and Rhyolite Mountain prove that such materials had once a much greater extent than they have at present. The general texture of the fragmentals is very fine grained, and bedding or other regular arrangement of fragments is for the most part wanting. In this respect these breccias and tuffs differ strongly from those of the larger volcanic area to the westward, where there is a rude but persistent bedding continuing for miles, and where much of the breccia is coarser than any found at Cripple Creek. The fineness of grain and the absence of arrangement in the materials of this district seem to speak for a formation by repeated explosive eruptions in a vent near at hand, or for quite violent outbursts whereby the fragments became finely comminuted.

Areal distribution.—In general the finer-grained and more homogeneous tuffs predominate in the northern and eastern portions of the area, although they may be found in any part. On Big Bull Mountain and northward to Grassy Gulch the tuffs are often very fine grained, soft, and crumbling, and evidences of rude bedding appear here and there. In the region of Gold Hill, Globe Hill, and Poverty Gulch the fine-grained tuff-breccias are more uniformly made up than in any other part of the district, though abrupt variations occur here also.

The tuffs, etc., of Mineral Hill and Rhyolite Mountain are very much decomposed, as a rule, though dark, purplish remnants occur on each hill in a few places. In the central and southern part of the area there is more rapid change in the character of the tuffs and breccias than elsewhere.

The most evenly bedded and fine-grained tuffs of the region were found on or near Bull Cliff. A shaft in the saddle between Altman and Bull Cliff cuts a very evenly bedded gravelly tuff, but other shafts near

by do not show such material. Again, at the southern end of the phonolite body of Bull Cliff some soft, friable, stratified tuffs are found, one of which exhibits a beautiful banded or concentric structure through arrangement of a delicate lilac coloring matter, after the manner common in weathered rocks.

There may be much more structure in the tuffs than has been discovered in the shafts and tunnels thus far opened, but there can scarcely be any regularity in the distribution of materials of various textures.

Andesitic tuff-breccia.—As regards the admixture of different rocks in the breccias, the extreme decomposition over much of the territory allows practically a discussion only as to the contents in andesite, phonolite, and granite. The first is the chief rock almost everywhere. Phonolite occurs in local abundance, and the débris of granite, gneiss, and schist is found sparingly all through the tuffs and breccias.

The freshest and most distinctly andesitic breccia or tuff is found in the eastern part of the district. On Battle Mountain, about the remnant of massive andesite, various prospects disclose dark-colored fragmental rocks consisting entirely of andesite of the type occurring in massive form. On the slopes of Big Bull Mountain purplish tuff prevails as far as exposed, and both tuff and breccia may be seen in shafts in Victor Pass and by the road leading to it at the head of Wilson Creek. On the northeast slope of Bull Cliff are two patches of massive andesite, shown upon the map; and here, too, it is very clear that the purplish tuff and breccia are chiefly made up of this same andesite. In the isolated patch north of Grassy Gulch, and also near the top of Tenderfoot Hill, partially bleached breccia or tuff may be found in which andesitic fragments can be recognized. In Rhyolite Mountain and on Mineral Hill purplish tuff-breccia is occasionally disclosed, and at the south end of the Mineral Hill body, near the Cripple Creek reservoir, is some very dark andesitic breccia. In the central and western part of the volcanic area the andesitic character of the tuffs may be seen at a few points, as on the ridge leading west from Gold Hill near the granite-schist border, in the ridge south of the Morning Glory mine at Anaconda, and east of the Elkton mine at the base of Raven Hill.

In a very large part of the area the fragmental rocks are so completely decomposed and bleached that the andesitic character of the débris can not be established, but must be inferred from the structure of the fragments as seen under the microscope and the fact that no other fresh rocks of similar structure have been found.

Phonolite-bearing breccia.—Phonolite becomes a prominent constituent of the tuff-breccia in certain localities. It is especially noticeable on the southern slope of Anaconda Ridge and on the ridge south of Squaw Gulch above the Morning Glory mine. In Raven Hill phonolite occurs in the tuff-breccia from the summit all over the western and southern slopes nearly to the granite line. These localities seem to belong to one area of phonolite-bearing material, distinct from the other

one of importance, which extends from the eastern spur of Battle Mountain almost to Victor Pass.

The phonolite is commonly recognizable only by its marked schistose structure, such as characterizes the dikes of the region, but occasionally moderately fresh fragments of some inches in diameter occur, as at the Morning Glory mine and on Anaconda Ridge. In sand and gravel-like grains it may have a wider distribution than has been indicated, in the more decomposed tuff-breccias of the district, but it is certainly not present in the oldest tuffs where the andesitic constituents are best preserved.

It would seem from the distribution of phonolite in the clastic material as if there might have been two vents of explosive outburst in the period of the volcano to which these tuffs belong, one near Anaconda and the other northeast of Battle Mountain. As will be seen later on, other indications point to the same conclusion.

Granitic débris in tuff and breccia.—Débris of granite, gneiss, or schist is found abundantly only in a few places. Near the summit of Mineral Hill the tuff-breccia is chiefly made up of angular granite gravel, and near the granite border about Guyot Hill a large amount of quartz and feldspar from these old rocks is present in the lower part of the tuff. As has been described in the preceding chapter, the microscope detects grains of microcline and quartz belonging to the granite in much of the tuff all over the district, and larger fragments are occasionally found in every part of the clastic formation.

It seems probable that the earliest explosive outbreak, by which the main conduit was formed, was so violent as to shatter the granite thrown out into fine sand and gravel, which may have been removed by erosion before the succeeding explosions in which igneous rocks were the chief ejectamenta. The High Park beds of Straub and Grouse mountains may represent this early granitic dust and gravel, collected in a lake contemporaneous with the earliest explosions.

THE BOUNDARY BETWEEN GRANITE AND VOLCANIC BRECCIA.

Relation to ancient topography.—A study of the contact between the granite and the fragmental volcanics gives information as to the general relations of these two geologic factors, and also tends to indicate the immediate position of the central vent. A glance at the map shows that the contact line between these formations is independent of present topography, and examination in the field has shown that in Rhyolite Mountain, Mineral Hill, and in the main area from the town of Cripple Creek through Tenderfoot Hill, along Grassy Gulch and south to Big Bull Mountain, and as far west as Victor, the fragmentals are resting upon an irregular surface of granite and schist, similar in configuration to that of the present day.

The tuffs of Rhyolite Mountain rest upon a granite slope dipping westward. The mass of Mineral Hill seems to occupy a north-and-south

valley, for on the north side the tuffs descend 500 feet nearly to Spring Creek, and on the south for 400 feet. In Tenderfoot Hill the granite surface dips in a southerly direction, and judging from the remnants on the north side of Grassy Creek there may have been an old valley nearly on the line of the existing one.

The large island of granite between Ironclad and Bull hills, and the smaller one of schist on the ridge between Gold and Globe hills, show how uneven the old granite topography was. It is possible that some of the minor irregularities of outline of the granite are due to faults, but no proof has been found of any dislocations sufficient to materially affect the conclusions to be drawn. What evidence there is upon this point will be presented in the next section.

From Grassy Creek to the limit of the tuffs on Big Bull Mountain is a rise of 900 feet, chiefly due to a northerly or westerly dip of the old granite surface. From Big Bull through Goldfield to the south base of Battle Mountain the fine-grained andesitic tuffs rest upon a northerly dipping granite surface.

The southwestern limit.—From Squaw Mountain across Arequa Gulch and through Guyot Hill to beyond Anaconda the contact plane dips so steeply to the northeast as to suggest that either there is faulting along this line or that portions of the actual crater walls of the center are here exposed. From the saddle between Squaw and Battle mountains the line descends 500 feet directly across the contours to the bed of Arequa Gulch, indicating a nearly vertical contact plane, and from Guyot Hill across Squaw Gulch to the pass on the trail between Anaconda and Cripple Creek the contact dips very steeply in places. A careful examination along this border zone did not give any proof of faulting as an explanation of the course of the contact, but did furnish some evidence tending to support the idea that the central vent or vents of the volcano were adjacent to this line. The principal evidence in this direction is the brecciated condition of the granite for some distance from the contact with volcanic breccia.

ROCKS BRECCIATED IN PLACE.

Within the volcanic area.—Before considering the brecciated condition of the granite in the places mentioned above, it may be well to present certain facts of observation as to the character of the fracturing to which the rocks of the central area have been subjected. In all portions of the district there has been a great deal of fissuring, often of great regularity, producing sheeted zones, and the ore veins of the district are especially connected with these fissures, as will appear in the discussion by Mr. Penrose. Such fissures are not by any means confined to the central volcanic area, but are found on all sides in the granite as well. At least a large part of this fissuring was later than the decomposition and the secondary induration of the fine-grained tuff of various parts of the district.

Of a quite different character is the irregular shattering or breaking up in place which massive rock has locally undergone. In many parts of the district, as at the Mattie D mine on Raven Hill, on the ridge northeast of Raven Hill, on Guyot Hill, and on Battle Mountain, there are small bodies of breccia consisting each of a single rock type, with little or no dislocation on the irregular fissures, and the conclusion is that such breccia is merely the shattering of a massive body in place. In some cases this material grades into a mixed breccia, as though the outer zone of the body had been so much shattered as to admit mingling with the surrounding tuff or breccia.

An instance of this local gradation is that of the phonolite body exposed by the Florence and Cripple Creek Railroad on the south side of Squaw Gulch, at Anaconda. In the railroad cut nearly massive phonolite is found, though much broken up. Going up the ridge toward Raven Hill a rapid change takes place by the admixture of andesitic fragments, and soon the breccia assumes the usual habit of the mixed variety. In many places the phonolitic material in the breccia seems restricted to the vicinity of a dike or small mass of this rock, and in such cases the contacts do not appear to be sharply definable. From these facts it seems probable that some earthquake shock, such as must be a common occurrence in a volcanic pile, had shattered the massive bodies in the loose tuff and breccia and caused a brecciation in place.

It is not improbable that such shocks have destroyed a bedded structure originally present in the tuffs.

In the border zone.—Near the contact along the southwestern border of the central area there is evidence that a similar sudden shock has caused the shattered condition of the granite. This is especially clear in the exposures along the Florence and Cripple Creek Railroad, north of Squaw Gulch, between the Blue Bell vein and the contact. It appears here that for several hundred feet from the contact the granite is brecciated, and fragments of a bleached igneous rock are also locally mingled with the granite. A careful examination shows, however, that this eruptive material comes from a number of narrow dikes in the granite, and that the whole mass is irregularly broken up with small dislocations in many ways. A nearly north-and-south parallel fissuring, such as the zone in which the Blue Bell vein occurs, has complicated this structure very much.

An irregular shattering of the granite is very marked on the slopes of Guyot Hill, especially toward Beacon Hill, and the same is true of the zone near the contact from Arequa Gulch over the pass between Squaw and Battle mountains.

Granite-breccia of Ironclad and Bull hills.—The granite island between these hills is practically a mass of granite brecciated in place by shattering, as seen in the Albany tunnel and in the surface workings upon the Wichita, Ironclad, and other claims, of all parts of this mass. Here, too, are small probable andesite dikes in granite, and

through the shattering and minor faulting a resemblance to a volcanic breccia rich in granite is locally produced.

THE MASSIVE ROCKS AND THEIR RELATIONSHIPS.

The massive rocks, which are clearly later than the main portion at least of the fragmental rocks, embrace considerable masses of phonolite, the nearly allied trachytic phonolite, nepheline-syenite, and syenite-porphyry, and numerous narrow dikes of phonolite, andesite, and various basaltic rocks.

Trachytic phonolite.—Three distinct masses of this rock are shown upon the map. One of them, extending from the northeastern base of Bull Hill to the north slope of Battle Mountain, is the largest mass of the district. The outlines assigned to this body are possibly inaccurate in various places, especially at the northern and southern extremities, for outcrops are rare, and the great decomposition to which all the southern part of the body has been subject renders an interpretation of this mass largely a question of judgment.

The character of the fresh rock is shown by outcrops near the Pikes Peak mine, by outcrops and prospect development in and about the town of Altman, by outcrops near the Buena Vista and Morning Star mines and near the northern extremity of the body, and in several prospects on the western slope of Bull Cliff. In connection with all of these exposures of comparatively fresh rock one may trace the gradation into the bleached porphyry, which forms the greater part of the mass. It may be that this area of massive rock consists of several distinct bodies in close contact, but no indications of such a compound character were observed.

The branching of the mass near the northern end is pretty clearly indicated by the ending of the breccia arm between. The eastern arm is a dike dipping steeply westward, as is proved by the workings of the Buena Vista mine, which are entirely in this dike. The incline shaft has a pitch of 70° (?) for 225 feet and does not disclose the contact of the dike, although at the surface it is only a few feet west of the shaft. It seems probable that the larger body of Bull Hill dips eastward and that it may descend for some distance nearly parallel to the contact of granite and breccia. At the southern end the irregularities are not very clearly defined. Small branch dikes from this body probably exist near the Moose mine and on the ridge northeast from Raven Hill, near the Rattler.

A small, irregular body of black, trachytic phonolite occurs near the top of Bull Cliff, forming a little shoulder on the southwest, and a larger mass, locally quite fresh, appears on the ridge above the Legal Tender mine. This body is cut by two narrow dikes of porphyritic rock, which are offshoots from the nepheline-syenite body on the west.

The trachytic phonolite is cut by phonolite proper and by basalt dikes, and is probably older than the nepheline-syenite.

Nepheline-syenite.—The single mass of nepheline-syenite occurring in the region is worthy of special notice as a probable indication of the immediate position of the central conduit of the volcano. Its borders are very poorly exposed, and the form of the mass is probably much more irregular than is represented on the map. The freshest granular rock is shown on the end of the little spur of Bull Hill south of the Independence town-site, and on the ridge north of the Legal Tender mine. Several small phonolite dikes cut this mass, but, as stated above, two apparent offshoots cut the trachytic phonolite.

As a granular rock, equivalent in chemical composition to the phonolite, it is to be assumed that at the time of its eruption this magma found conditions of cooling so different from those attending the solidification of similar phonolitic magmas as to produce the observed granular structure. As a result of this difference in structure one would ordinarily infer that the granular rock had consolidated at a much greater depth than the neighboring trachytic phonolite, but this seems possible only by assuming great variation in the volcanic mountain at different times. It is possible, however, that if the nepheline-syenite magma was injected at the close of a period of eruption that had built up a considerable cone, and occupied the heated conduit, the conditions of slow cooling supposed to be necessary to the production of the granular structure may have been realized. The presence of some peculiar factor in the magma itself would seem to be the only other explanation of this occurrence.

Syenite-porphyry.—The triangular area of syenite-porphyry on the southeastern spur of Gold Hill is, like that of the nepheline-syenite, suggestive of local conditions which caused an unusually coarse-grained texture to the magma cooling at this point. It happens that this mass occurs between the brecciated granite areas of Ironclad Hill and of the contact zone near Anaconda, and adjacent to the especially marked phonolite-bearing breccia of Anaconda Ridge; so there is some ground for the suggestion that a minor vent of eruption is situated at this point. This idea will be reviewed below.

Andesitic dikes.—Dike eruptions of andesite took place in some portions of the volcano long after the earliest massive flows of this rock, but their exact place in the sequence of magmas is not fully known. One of these andesites is the micaceous andesite of Battle Mountain, whose biotite is quite fresh, while augite and hornblende, which were probably both associated with it, are entirely decomposed. This rock contains large apatite crystals like those of the earlier andesite, and the two types are much alike. The later andesite occurs on the west slope of West Battle Mountain, in the saddle between the two summits, and on the northeastern slope, as described more fully in the next chapter, but owing to poor exposures and apparent irregularities of the contacts, perhaps from the shattering by earthquake shock, it was impossible in the time available to outline these dike masses with satisfactory accuracy, and they are omitted from the map.

In the southwestern part of Anaconda Ridge are several dikes of a pyroxene-andesite. One of these dikes, cut by the Anaconda tunnel near its mouth, is of a dark, nearly fresh rock. Others are here and there exposed in prospect shafts and tunnels. This special type has not been found elsewhere in the district.

In Poverty Gulch two andesitic dikes of some importance occur. One is just above the Gold King mine. Here and there all over the region occur other small dikes, which may be andesitic in character, though they are commonly too much decomposed for nearer determination.

Phonolite.—This most characteristic and important rock of the volcano was erupted at several periods, and very much more abundantly than any other type. It occurs in the tuff-breccia of the middle period, in several massive bodies, and in very numerous dikes both within and about the central area. It is of such importance that a special section is given to it (see p. 68).

Basaltic dikes.—One of the most interesting features of the region is the number of narrow basaltic dikes of a very late period of eruption, which are found all through the southern part of the tuff-breccia district. As shown in the petrographical chapter, these dikes are mainly of two classes, one a nearly normal feldspar-basalt, the other a nepheline-basalt. By reason of their richness in olivine, nepheline, and iron-bearing minerals these dike rocks are almost invariably extremely decomposed, and their presence would hardly be suspected were it not for the developments in mine workings, where comparatively fresh rock is occasionally found.

The more normal basalt is represented by dikes in the Wilson mine near Altman, and one near the Dolly Varden shaft in Squaw Gulch. To this type may be assigned a few others known in Bull Hill, near the Zenobia, at the Lucky Guss, Eagle, and other shafts.

The nepheline-basalt is best shown in the Elkton and Raven mines, where a dike is opened in many places, and quite black, fresh rock has been found. The Anna Lee and Black Diamond workings on Battle Mountain expose another one of these dikes—at the latter place in comparatively fresh condition. Other dikes, probably of this type, are shown at the Moose, Kentucky Belle, Ben Harrison, Trail, and other mines in Arequa Gulch. Several occur in Battle Mountain, but it has not been possible to map many of them accurately, and the fact that in decomposed condition several of these basaltic dikes are ore-bodies (Moose, Raven, Anna Lee, etc.,) makes it undesirable to generalize at all in representation upon the map.

The order of eruption.—The earliest rocks of this vent were andesites of intermediate chemical composition. Then came a series of allied phonolitic rocks, all rich in alkalies and moderately so in silica, and at the close a limited number of small dikes of basic rocks, the basalts, which contrast very markedly with the phonolites.

As was brought out in the discussion of this phase of the subject in the preceding chapter, these variations in chemical composition of

the magmas of this district, considered in connection with the order in which they were erupted, are in accord with many other observations in volcanic centers, and may be taken as confirmatory evidence as to the true character of the district.

These dikes are most numerous in Battle Mountain and the eastern part of Raven Hill, and by their restricted occurrence they give some additional weight to the idea that the principal conduit of the volcano is probably in this part of the area.

IMPORTANCE OF PHONOLITE.

The characteristic rock of the volcano.—The Cripple Creek district is especially characterized by the abundance of phonolite, including with it the nepheline-syenite and trachytic phonolite. As brought out elsewhere, it is a rock of rather unusual chemical and mineralogical composition, and its abundance here and rarity elsewhere make it one of the most noteworthy features of this center.

Phonolite was repeatedly erupted, as shown by its presence in a part of the tuffs and breccias as one of their constituents, and also in dikes which cut such material. It is probable that the dikes themselves belong to several periods, and the related rocks—nepheline-syenite and trachytic phonolite—must belong to distinct periods.

Distribution.—An examination of the map shows that the narrower phonolitic dikes in the central and southern portions of the district have a rude radiating arrangement with regard to the supposed central vent, but that on the north no such order can be made out. The dikes of this character are not abundant in the country surrounding the district covered by the map, but they do occur in decreasing number for several miles on all sides beyond the map limit.

The larger masses, such as those of Straub Mountain and Grouse Mountain, are also found on all sides, and this is the only rock type of the volcano having any such distribution beyond the immediate vicinity of the central vent. All of these larger phonolite masses appear to be dike-like bodies in granite or in the grits of the High Park lake. Their character seems shown by the occurrences of Grouse and Straub mountains. In these cases the evidence is clear that the phonolite was injected laterally nearly on the line between the High Park grits and the surface of granite or of rhyolite upon which they rest, lifting up fragments of both in several places, as shown by the map. The flat-dipping dikes in granite on the west of the center, such as the long one north of Grouse Mountain, that west of Mound City, and that west of the town of Cripple Creek, all seem to show that the fissures filled by these magmas were deflected as they approached the surface from the steeper courses they occupied in depth, and owing to the rapid disintegration of the granite above and around these masses they now frequently occur as cappings of cone-like points, with a distinct dip of the lower contact on some side of the mountains corresponding to the

surface of granite below the phonolite. In the cases of the phonolite bodies on the north slope of Big Bull Mountain, the hill lying north of it, on the north side of Grassy Gulch, Rhyolite Mountain, and Mount Pisgah, the phonolite seems to have followed nearly the surface between the granite and tuff or breccia of the volcanic cone.

GASEOUS EMANATIONS OF THE VOLCANO.

Reasons for assuming a fumarole period.—The physical facts of the Cripple Creek volcano and the succession of magmas which have been erupted appear to warrant the conclusions that the history of this vent has been unusually complete, and it is then quite logical to ascribe the great decomposition of the rocks to the agencies known to accomplish such results in the dying-out periods of observed volcanoes. Especially in the fact that phonolite is the peculiar product here, and that its magmas were repeatedly erupted in the later phases of activity, is found reason to assume important periods of fumarole or solfataric action. The phonolite magmas contained sulphuric acid, chlorine, and fluorine, as shown by the nosean, sodalite, and lavenite of the rock, and it would be quite unnatural to assume that the periods following the eruptions of such magmas were not in some degree characterized by gaseous exhalations.

Evidence of fumarole action.—It is impossible now to distinguish with certainty the effects of the gases in question from those produced by the same agents when contained in solution in the hot circulating waters which must be assumed to have characterized the last period of the volcanic cycle. Little direct evidence of the action of either chlorine or sulphuric acid can be found in the secondary minerals now preserved, and it may be that the sodalite and nosean of the phonolite took up nearly all of these agents contained in the magma; but fluorine is so abundant in fluorspar, in various modes of occurrence, as to suggest that it may have been the principal element of the fumarole period.

Sulphur is not found here in combinations suggesting distinct solfataric action, as is the case in the Rosita volcano,[1] where the writer found alunite to occur in considerable masses resulting from the decomposition of rhyolite, quite as in some of the volcanic districts of Europe. Gypsum occurs in the Deerhorn mine on Globe Hill, but in ore veins, and it is most probably the result of aqueous action.

Fluorite is a rather characteristic mineral of the region, but it usually occurs in ore veins or as crystals in pores of otherwise much altered rocks, and hence seems to occupy places indicating that it is a formation of one of the more recent periods of aqueous action.

[1] On alunite and diaspore from the Rosita Hills, Colorado. Am. Jour. Sci. (3), Vol. XLI, 1891, p. 466.

CIRCULATING WATERS.

Several periods.—As already stated in the preceding section, it is impossible to separate into distinct groups the products of gaseous and aqueous decomposing agencies acting upon the heterogeneous volcanic pile. It is clear, however, that there were several periods during which heated solutions circulated through the permeable fragmental rocks or in the many fissure systems of both clastic and massive rocks. The discussion of this matter is naturally assigned in greater part to the report by Mr. Penrose on the ore deposits, for these were formed during this period of circulating waters, but from the standpoint of general geology it is also of interest to note the several stages of this period.

It is often to be noted that the ore veins occupy very sharply defined fissures in fragmental rock, and it is evident that prior to the formation of the fissures the loose and permeable tuff and tuff-breccia must have been indurated by extensive decomposition, resulting in silicification, kaolinization, or muscovitization.

Perhaps the two periods thus indicated correspond to those in which large masses of bleached tuff and breccia were first impregnated with pyrite, and then rendered porous by its extraction. It seems more likely, however, that the latter action belongs to the still later time during which ore bodies have also been acted upon.

It is interesting to note that both the earlier decomposition and ore deposition may actually belong within the general epoch of the volcanic action, and that after them came an expiring outbreak of explosive forces. Such, at least, is the apparent significance of the small vent near the Moose mine on Raven Hill (described in Chapter IV, p. 90), where in the midst of much decomposed tuff penetrated by ore veins there is soft and crumbling tuff, of peculiar constitution and carrying so many fresh fragments of phonolite and andesite as to make the conclusion almost a necessity that a small vent is situated at the point in question. It is hardly conceivable that the tuff of this locality can be merely a part of the general formation which has escaped decomposition.

This bit of evidence is apparently confirmed by an occurrence of black, fresh limburgite in the silicified tuffs of Bassick Hill, an outlying vent of the Rosita volcano, described by the writer some years ago. The small dike of black rock contains many very fresh olivines, while cutting an andesitic tuff and agglomerate which is very completely bleached and silicified. It is plain that this very basic dike must be regarded as a last injection of the Bassick vent.

SEQUENCE OF PHENOMENA.

As far as the sequence of physical phenomena at this center of eruption can now be made out it was one typical of a volcano. Probably the earliest event was an explosive outburst through the granite,

producing the conduit through which the volcanic forces found relief in many subsequent periods. But it is true that very little granite débris is found in the tuffs and breccias, and that it is seldom abundant even in the lowest parts of the fragmental accumulations. In this connection the observations of Sir Archibald Geikie among the deeply eroded volcanic necks of the Firth of Forth in Scotland are highly significant.[1] He found that certain necks were entirely filled by débris of the older rocks through which the channel had been made, while others contained varying amounts of igneous matter, even to the total exclusion of older rock fragments. From his observations the conclusion was reached that the volcanic channel may be formed originally by a violent explosion that is not necessarily followed at once by ejection of igneous matter, and that repeated explosive outbreaks are necessary to completely clear the channel of country-rock fragments.

The scarcity of granitic débris in the lower portions of the tuffs and breccias resting on granite about the Cripple Creek center has suggested that the earliest outbursts were very violent, breaking the granite into small particles, and that little if any igneous material was ejected at the first eruption. If a quiet interval of some duration then followed, it would seem natural that the ordinary agencies of transportation would remove the fine débris to a large extent. It is a fact of observation that the débris was removed, whatever the agency may have been. And the grits of Straub and Grouse mountains, which have been correlated with the High Park lake-beds, seem to belong to the volcanic period and to be composed, in fact, of just such angular granitic débris as may be assumed to have resulted from the first volcanic outbursts. The possibility that these lake-beds are of this character has been discussed in describing the formation in the preceding chapter.

From the description of the rocks of the district and their associations it is clear that during the active period of this volcano there was a series of eruptions of various lavas, alternating to some extent with explosive outbursts. With the exception of the earlier andesite, none of the massive rocks now seen represent actual lava-streams, but it may be assumed that lavas corresponding to the dike rocks were erupted and have been completely destroyed by erosion. The earlier andesite remnants belong to the inner portions of some large surface mass.

The evidence concerning the dying-out period of activity has been reviewed, and it would appear that the sequence of events has been almost theoretically complete in the history of the Cripple Creek volcano.

AGE OF THE VOLCANO.

The evidence as to the age of the volcano is rather indirect and circumstantial. The first records of volcanic eruptions in this part of Colorado are contained in the tuffs and conglomerates of the post-Lar-

[1] Trans. Roy. Soc. Edin., Vol. XXIX, 1880, p. 437.

amie beds in the Denver Basin, near Canyon City, and in South Park,[1] and it seems probable that in this general region volcanic eruption continued with intervals of quiet from the close of the Cretaceous down to late Tertiary times. As far as known, the post-Laramie eruptions produced nothing but andesite and local basalt flows, the latter in the Denver region.

It is not known what interval of time was covered by the eruptions of the district south of South Park, but at Florissant the well-known Eocene (Oligocene) lake-beds are composed of volcanic ash and are themselves overlain by breccia and agglomerate belonging to that large volcanic district. Rhyolite also rests upon the Florissant beds and upon various tuffs, etc., of the western volcanic field, as was found in mapping the Pikes Peak area. The only direct evidence concerning the age of the Cripple Creek volcano is connected with these rhyolite remnants, as is brought out in discussing the relation between the rhyolite and the High Park lake-beds of Grouse Mountain (pp. 107–108).

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[1] Whitman Cross: Post-Laramie deposits of Colorado. Am. Jour. Sci. (3), Vol. XLIV, 1892, p. 19.
R. C. Hills: Orographic and structural features of Rocky Mountain geology. Proc. Colo. Sci. Soc., Vol. III, 1891, p. 359.

CHAPTER IV.

DESCRIPTION OF THE CENTRAL AREA.

The area to be described in this chapter includes the fragmental volcanics with the massive rocks penetrating them, excepting the outlying remnants of Mineral Hill and Rhyolite Mountain, which can best be treated in the next chapter. Beginning with Battle Mountain, the southern hills about the supposed central vent will be described, followed by those of the northern part.

In referring to mines or prospects whose location is shown upon the map by a star, this fact will be indicated by a star in brackets.

BATTLE MOUNTAIN.

General description.—Battle Mountain is the southernmost hill of the volcanic center, and contains several of the important rock formations of the district. It has smooth slopes, bare except on the north, with few distinct rock outcrops, although the slide or wash is not deep, and the numerous trenches and prospect pits reveal the rock in place quite clearly. On the steep northwestern slope is a growth of aspens reaching to the summit. There are two rounded summits, and a high saddle separates it from Squaw Mountain.

The main formation of Battle Mountain is fine-grained volcanic breccia or tuff, in various stages of decomposition and induration. At the southeastern base the massive augite-andesite of earlier date than the breccia may be very clearly seen, and about it the character of the tuff and breccia is well illustrated.

In the upper part of the mountain occur small masses of a mica-bearing andesite cutting the breccia, but not sufficiently well exposed to admit of accurate mapping. There are also numerous dikes of phonolite and several of basalt. Some of these are indicated upon the map. On the west and south the volcanic rocks of Battle Mountain are bounded by the granite contact, which is more clearly exposed than usual, as will be described.

Nearly all the volcanic rocks of the mountain are much decomposed. The productive mines on its slopes have made it one of the best-known portions of the district.

Tuff and breccia.—The fragmental rocks of Battle Mountain consist almost entirely of andesitic débris, and in the immediate vicinity of the massive andesite body shown upon the map one may plainly see that

the tuff and breccia are mainly made up of that same andesitic type, identifiable especially by its large, glassy apatite crystals. At the Independence No. 4 shaft [*] and in the drain east of the Portland mine, as well as locally all around the border of the andesite mass, the dark colors of the partially altered tuff may be seen.

In the greater part of the mountain mass the fragmental rocks are usually so much bleached that the andesitic nature of the material is obscured or wholly obliterated. Granitic débris is nowhere abundant in the tuff and breccia excepting along the southwestern border, but it may appear at any point in distinct fragments, and the microscope usually reveals minute grains in subordinate amount.

Phonolite appears in the breccia on the northeastern slope of the mountain, and is common in it from this point to the south base of Bull Cliff.

The tuff of Battle Mountain is usually very fine grained, and when bleached and indurated, as it is in many places near the summit and down the northern slope to Arequa Gulch, it appears to be a massive rock. In some cases only intimate acquaintance with its various stages of change permits identification, and occasionally it becomes impossible to distinguish with certainty between massive rocks and indurated tuffs, except by microscopical study. No bedding was observed in any of the fragmental rocks of this locality.[1]

The indurated massive-appearing tuffs are often bluish-gray or white and abundantly impregnated with minute pyrite crystals. More frequently, however, the pyrite has been leached out, leaving the rock variously stained by hydrous iron oxide, porous, and of light weight.

The contact with granite.—From Arequa Gulch up the steep slope to the saddle between Squaw and Battle mountains the contact line may be closely located by the numerous prospects on either side, but its exact character is not well shown. As brought out in the preceding chapter, this portion of the boundary of the volcanics is so clearly a very steeply dipping plane that it seems possible that it is a part of an actual crater wall.

The contact passes between the Sunset and Eclipse [*] tunnels in Arequa Gulch and then runs up to the Coriolanus shaft in the saddle, bowing slightly to the west. For several yards at least from the contact the granite is much brecciated, but only immediately adjacent to the volcanic breccia is it porous through the removal of quartz and mica. A few yards from the line the breccia becomes quite massive, and contains little granite. One of the shafts on the Little Mary claim, on the northwest slope, passes through breccia into granite, or at least strikes the contact, and the same is true of the Coriolanus shaft. Neither shaft was accessible at time of visit, but the line

[1] The statement of Mr. C. J. Moore that bedding is distinct in certain parts of the mountain seems to refer to jointing planes dipping at low angles, and not to any original arrangement of materials. See discussion of the author's cited paper read before Colo. Sci. Soc., June, 1894, p. 23 of pamphlet.

certainly passes through or just west of the latter shaft at the surface, as shown by adjacent holes in granite on the west. At both of these shafts the porosity of the granite contact zone is marked. Minor faults or irregular dislocations may produce small irregularities in detail on the northwestern slope, but they are unimportant.

Passing south from the saddle the contact turns diagonally down the slope, swinging more and more to the east. It passes a short distance below the Dead Pine shaft and then runs nearly due east to the ravine west of the Portland. Various shafts on the Granite and Queen of the Hills claims locate the contact very closely. On the eastern bank of the ravine the line turns abruptly to the south, as indicated on the map, to a point nearly west of the Independence, where it swings again to the east, passing directly under the new shaft house of this mine a few feet north of the shaft, and it continues in this direction until concealed by the alluvium of Wilson Creek.

At the Independence the contact is shown to dip northward at about 30°, and on the little ridge southwest of the Portland an easterly or northeasterly dip is shown by shafts penetrating breccia into granite near the boundary. From the nature of the case the angle and direction of the dips of the surface upon which the breccia rests must be very irregular, but upon the theory that the main vent lies just north of Battle Mountain only those shafts which are located near the boundary—as the Dead Pine, Portland, and Bobtail—are likely to reach granite except at great depth.

Massive augite-andesite.—A body of massive andesite extends from near the summit of Battle Mountain down to and across Wilson Creek, under Goldfield. It forms a little projecting shoulder of the mountain and is exposed in outcrops and by numerous pits. The outline given by the map is generalized, for in nearly all parts there is a kind of gradation from massive rock, shattered but not dislocated, into mixed breccia clearly made up of the same rock in predominant degree. This is interpreted to mean that an explosive outburst through a larger mass of this andesite shattered it and produced a tuff or breccia largely composed of its débris in the immediate vicinity. The general form of the mass remaining is shown by the map. It is dark-colored in places, but is generally more or less bleached.

Just north of the summit of Battle Mountain, and a few yards east of the Anna Lee basalt dike, is a small patch of this same andesite, exposed in a single prospect pit. It may be a large fragment in the breccia or a sharp point of the main andesite mass surrounded by distinct breccia. Other projecting parts of this massive rock will doubtless be indentified on careful examination, as the prospecting developments multiply.

Mica-bearing andesite.—Battle Mountain is specially characterized by small bodies of another andesite, described in Chapter II, which has, as a rule, many distinct flakes of brown mica, but is a type closely allied to the preceding one, for augite was once prominent in it, and both have

the remarkable large apatite crystals. This second andesite type is later than the breccia, for its dense contact zones were found in several places, but it was found impossible to outline the masses satisfactorily, owing to poor exposures, and they have been omitted from the map. It was found that some of the bodies were much smaller than one would infer from the slide rock, and also that either shattering by violent shock or dislocation by small faults had rendered tracing of outlines very difficult.

The largest mass of this micaceous andesite extends from the saddle on the north up the northeastern slope of the mountain nearly to the top. The Wisconsin shaft [*] is on its eastern contact and several prospects are in it down nearer the saddle. Between the two summits of the mountain the rock is shown in several places, and a dike apparently runs from the eastern side of the saddle southerly to the Granite claim, where a shaft near the north end of the claim is sunk on the contact; but exposures were insufficient to outline the dike. On the west side of the western point of the mountain is another indistinct dike running west of south down the slope nearly to the granite. A narrow dike of the same rock was cut in the Eclipse tunnel in Arequa Gulch.

Phonolite dikes.—Typical phonolite dikes are numerous in Battle Mountain. Most of them run nearly northwest and southeast, but curve as shown on the map. There are many more than could be represented, and they fork in a complicated manner, which may be frequently suspected without clear evidence. Such curving and splitting as is represented in the map of the Independence vein and dike by Mr. Penrose (Pl. XIV) undoubtedly occurs very frequently, but can not be traced except where numerous pits have been sunk. As the dikes run so nearly parallel to many ore veins and their walls are natural planes for the prospector to investigate, it seems best to omit from the map the generalized representations, which could alone be made, of the many dikes indicated here and there by isolated prospect shafts.

Between the Independence and Anna Lee mines and in the workings of the Portland there are several narrow dikes whose relations to one another have not been sufficiently revealed for mapping. Those of the eastern slope shown upon the map are outlined by various pits and trenches. On the slope north of east from the summit there is a complex of dikes, one of which is probably an extension of the one passing near the Blue Bird shaft. The dikes represented vary much in width, from less than 10 feet to 40 or 50 feet.

Beyond the line of breccia on the south the phonolite dikes of the Independence and Strong mines can be more easily followed, and there are several others in the same general strike, especially near the Independence.

There are fewer phonolite dikes in the western part of the mountain. One narrow dike passes very near the Dead Pine shaft, and others are shown here and there in isolated pits.

In nearly all cases the phonolite is white, through kaolinization. At the old Washington shaft fluorite crystals are sprinkled through the much-decomposed rock.

Basaltic dikes.—The narrow basic dikes of the last eruptive period of the volcano are represented in Battle Mountain by the Anna Lee and Agnes dikes. The former can be traced northward, through a series of surface openings over the top of the mountain, and it may be one of the dikes in the ravine below the Trail mine. To the southward this same dike seems to run just a few yards east of the Portland, and to be also exposed in the Black Diamond, but it is quite possible that several parallel dikes occur, and that all these openings may not be actually on the same dike.

The dike at the Agnes could not be traced far enough for mapping. A shaft in granite very close to the contact, above the sampling works in Victor, shows one of these nepheline-basalt dikes beyond the volcanic line, and in an unusually fresh condition.

In the Black Diamond workings the dike was locally encountered in exceptionally fresh condition as a black rock, dense except for large glassy or partly serpentinized olivines. In general this rock is much decomposed, yielding a green, soft material, and, as described by Mr. Penrose, the decomposed dike may become practically an ore vein, and contain ore shoots, as at the Anna Lee. There are unquestionably more of these basaltic dikes in Battle Mountain than are now exposed.

Local vent in granite, near Victor.—The cut in the first granite ridge west of the town of Victor, on the Florence and Cripple Creek Railroad,

FIG. 1.—Section of vent in granite near Victor.

discloses what seems to be a little vent of explosive outbreak, which is unique in the district. The accompanying figure shows the north bank of this cut. In the middle, where the bank is 15 feet high above the track, is a section of a fissure in granite, about 40 feet across, which is filled by a mixture of dark, reddish-brown particles, with granitic gravel, much iron stained, as a matrix. The dark-brown fragments are seldom more than 1 inch in diameter, and are often rounded, resembling lapilli. They apparently belong to andesite, but are so heavily impregnated with iron oxide that their exact character can not be definitely made out. All dark silicates have been decomposed. Some of the particles are porous.

The material is but slightly consolidated and disintegrates rapidly on exposure. Thus a dump of a shaft sunk in it a few yards north of the railroad has crumbled into a gravel-like mass. Other shafts explore it south of the railroad, and the form of the mass seems to be oblong, as shown on the map.

The granite either side of the tuff is very markedly fissured in several places, the fissures dipping very steeply eastward, and it is clear that parallel fissure planes traverse the tuff. These fissures produce narrow, sheeted zones in places. The strike of the planes is N. 10° to 15° W.

BIG BULL MOUNTAIN.

General description.— Big Bull Mountain consists principally of granite, but on its northwestern slope are found massive andesite, phonolite, and tuffs of the main volcanic area. As the chief interest of the mountain attaches to these formations it will be described in this place.

The mountain is an exception to most of the elevations of the district, in that it is rather densely covered with a heavy growth of spruce, which is rapidly disappearing to furnish lumber and firewood for the mining interests. It has a flat top, with steep slopes on all sides. There are probably some phonolite and diabase dikes in the coarse red granite on all the slopes, but only a few small ones, which could not be traced out, were found in the traverses made around and across the mountain. Veins of sufficient strength to attract prospectors occur sparingly in the granite, but none has been proved of much value as yet. They are mainly narrow fissures adjacent to which the granite is decomposed and somewhat mineralized. Some veins seen on the south side are filled by attrition material, as though on faults.

Tuff and breccia.—The fragmental volcanics of the northern slope are largely covered by an aspen growth, but numerous prospect holes show the general limitation and character of this formation quite distinctly. It is for the most part loose, crumbling, gravelly tuff, often purplish in color and carrying small granite fragments, but as a rule it is bleached to bluish, gray, and yellow hues. It connects with the similar material of Battle Mountain, and from the course of the boundary it seems to be resting upon a northwesterly dipping granite surface. The tuff rises to the 10,700-foot contour on the north ridge of the mountain, but does not extend down the eastern slope below the phonolite body, at least not in continuous mass, though holes close to the phonolite show it here and there. At the Little Hatchett [*] claim several prospect shafts sunk in granite or tuff near the main boundary line prove irregular relationships not explained by the present workings. There may be faulting at this point.

Massive augite-andesite.—At the western base of the mountain, under the town-site of Goldfield, is a ledge of dark andesite forming the eastern end of the Battle Mountain body, already described. It is exceptionally fresh at this point. A narrow rim of tuff seems to separate the andesite from the granite, though the latter probably underlies the andesite, unless there is a tuff of still older origin.

Another small exposure of the same andesite appears above Goldfield, but the largest remnant of the rock in the district occurs at the north base of Big Bull Mountain, coming in contact with granite on

the east. This mass is shown chiefly by prospect holes, but on the Alfalfie, Little Caddy [*], and Olive Branch [*] claims are shafts 50 feet or more in depth in this rock. It is more bleached than that of the lower ledges, but the microscope proves the identity, and it is also indicated by the large apatite crystals.

All of these masses are thought to be remnants of a large body, and they are very possibly still continuous under the tuffs.

Phonolite.—On the northern slope of the mountain is one of the peculiar occurrences of phonolite which characterize the country for several miles about the volcanic center. The boundary of this mass is indicated by a ledge outcrop nearly all the way around, rising as much as 20 feet in places. The rock is fresh, greenish-gray, dense, very fissile, the structure planes dipping gently down the northern slope in most places, and seeming to correspond to the surface of granite or of tuff upon which the apparent sheet rests. The ledge face is due to joints nearly normal to the fissile structure. There are places, however, where the fissile structure stands nearly vertical.

The contacts are concealed by talus of thin, ringing sherds, as is natural from the structure possessed by the mass. A narrow band of tuff runs in between the granite and phonolite on the south, and from the evidence of holes on the eastern side it is probable that a thin layer of tuff separates the two massive rocks, at least locally, on this border. This body seems to be a lateral injection, probably from the northwest, following approximately the contact between tuff and granite.

On the top of the mountain a sheet of phonolite lies upon the granite of the southwestern shoulder. It is almost entirely covered by timber except on the north, is broken up into rough tabular fragments by weathering, and its relations to the granite can be inferred only from the fact that it does not extend down any of the steeper slopes more than a few feet. This body is much more decomposed than the other. Débris from it is scattered all over the southern and western slopes of the mountain.

HILLS EAST OF BULL CLIFF.

Lying to the north of Big Bull Mountain and east of Bull Cliff are two small unnamed hills on the border of the volcanic area. They show phonolite and tuff, with the granite line very clearly marked in the easternmost hill.

Volcanic tuff.—Surrounding the phonolite mass of the larger hill is fine-grained, crumbling tuff of grayish and yellowish colors, too much decomposed for clear determination of its constituents, but never indurated as in the main area to the westward. Naturally this material does not form outcrops, and only the numerous prospect holes reveal the character of the formation underneath the grassy or aspen-covered slopes.

The eastern border of the tuff is pretty well defined by the outcrops of granite just beyond it, at least in the upper part of the eastern hill.

The curving ridges north and south from this point are of granite, while holes show the presence of tuff on the western slopes of these ridges. The gentle slope down to Grassy Gulch is underlain by tuff, though the eastern border is not well defined.

No coarse breccia was found in these hills, and, as in Big Bull Mountain, the meager evidence indicates that the tuff lies upon a granite surface with a general northwesterly dip.

Phonolite.—Two sheet-like masses and three small dikes of phonolite occur in this area. The larger phonolite body caps the larger hill, and its boundary is indicated by a ledge outcrop on the south, east, and north, although it is not so distinct as about the mass on Big Bull Mountain. Contacts are everywhere concealed by loose phonolite débris.

On the west the phonolite thins out, but whether it continues as a thin sheet dipping westward is not shown by present explorations. However, shafts on the N. O. Johnson claim, only a few yards east of the western limit as shown by the map, do prove a considerable thickness of the phonolite. One of them, about on the 10,200-foot contour, passes through phonolite into tuff, here distinctly stratified. The shaft was nearly full of water at time of visit, but its depth must have been more than 50 feet, judging from the dump. The vesicular and fluidal structure of a part of the phonolite here found may be explained as belonging to the lower contact zone of the mass.

The smaller hill has two little summits, the western of phonolite, the eastern of granite, while a band of tuff between them causes the little sag, as is proved by several pits on either side. The phonolite body appears to be a westward-dipping sheet nearly on the contact of tuff and granite. Both of these larger phonolite masses are of nearly fresh, greenish-gray rock of the usual type.

The three dikes of phonolite occur in granite, tuff, and andesite respectively. The one in granite is 3 or 4 feet wide, and though so near the capping body of the hill, a connection could not be proved. The other dikes are shown only by shafts sunk on one wall, giving the directions of the map. They are covered by soil, and their thicknesses are unknown. Other prospects near by in tuff or andesite show them to be small dikes.

BULL CLIFF.

General description.—The name Bull Hill has been generally used in the past to include both of the elevations near Altman, but as they are quite distinct topographic features deserving recognition the name Bull Cliff is here applied to the lesser, eastern point, in accordance with a usage already practiced among local miners. It was upon this summit that the striking miners constructed their log fort during the memorable labor troubles of the summer of 1894. The northern and eastern face of the summit is a cliff 50 to 75 feet high, of a peculiar rough phonolite, with a rude columnar structure. For purposes of description,

this section will include the slope northward to Grassy Gulch and the ridge on the south leading down to Goldfield. Pl. XII shows the northern cliff as it appears from the Buena Vista mine.

As in most of the hills of the central area, volcanic tuff and tuff-breccia are the principal formation, but there is a greater variety of later massive rocks than in the hills thus far described. The summit mass of the cliff is a peculiar phonolite, and narrow dikes of the same rock are more numerous than is shown by the map. On the west is an arm of the large trachytic phonolite body of Bull Hill, and two other masses of the same rock occur, one of them near the end of the ridge to the south. In this same ridge is the eastern end of the nepheline-syenite mass. On the northeastern slope are several small exposures of massive andesite similar to those already described.

Tuff and breccia.—The fragmental rocks of Bull Cliff and vicinity are tuffs and tuff-breccias, seldom very much indurated, and over a large part of the surface the andesitic character of the material can be clearly made out. Especially on the northeastern slope, below the Victor mine, the purple dumps of tuff are very conspicuous. About the andesite exposures the fragments in the tuff are easily identifiable, and shafts between the two andesite patches of the map pass through tuff into massive rock. The tuffs are usually quite fine grained, but at the Little May mine and in Victor Pass some fragments a foot or two in diameter occur in the finer-grained material.

In spite of the fine-grained texture a stratified arrangement is seldom found, although it is also true that the most marked instances of bedding found in the region were about Bull Cliff. Thus in the saddle between Altman and Bull Cliff and at the south end of the phonolite body of the cliff prospect holes have revealed thinly bedded tuffs of white or light-yellow color, occasionally very beautifully colored in concentric or irregular bands by weathering.

The rapid changes in constitution shown in depth by single shafts and by adjoining ones in regard to lateral variation are very marked in numerous places. A shaft by the roadside south of Victor Pass shows red and gray fine-grained tuffs, coarser tuff, breccia, and a noteworthy rock in which fragments of augite-andesite, with apatite crystals, are embedded in a fine red mud or ash. Near this shaft to the west and north, on slightly higher ground, pits show phonolite-bearing breccia and tuff, the relations indicating that the latter rests upon the pure andesitic tuff.

Phonolite appears very locally in the tuff-breccia of a small area on the northeast slope near the Midland Terminal Railroad line, and here shafts pass through it into the purely andesitic rock. These facts all seem to show that the andesitic tuff, etc., rests upon an uneven surface of a massive andesite, small portions of which have been exposed by erosion, and that the phonolitic tuff-breccia is later and fills hollows in the earlier tuffs.

Purplish or dark colors, due in part to the andesitic material, characterize much of the tuff-breccia on the north and east slopes of the hill, but on the west there is much more extensive bleaching and induration.

Augite-andesite.—The small areas of massive andesite below the Victor mine have been referred to above, and from the shafts which pass through tuff into massive rock in several places it is plain that a considerable body of andesite is present beneath the tuffs. In fact, from Victor Pass northwestward over the entire lower slopes of Bull Cliff and Bull Hill, it would not be surprising to find massive andesite under the fragmentals at small depth. Near the road, at the south end of the main phonolite mass, are several holes in massive rock surrounded by breccia.

Trachytic phonolite.—The arm of this rock which branches off from the main body north of the Buena Vista mine and passes along the western slope of Bull Cliff is very well outlined in most of its course by prospect openings. It seems to be a dike ascending from the west at a steep but probably variable angle. The south end is not well exposed, and there is probably a narrow dike extension to the southeast as far at least as the Victoria No. 2, at the forks of the road on the ridge.

While the rock of this broad dike is often much decomposed, it is found in very fresh condition in several prospects. The rock of which a quantitative analysis was made (see p. 43) came from a shaft on the southwest slope of the cliff. When fresh it is black, with many crystals of feldspar, nosean, and augite, in a dense ground-mass, and does not have the usual fissile structure of the typical phonolites.

A small oblong dike of this rock causes the little southwestern shoulder of the hill. It may be an offshoot from the adjoining dike, but is probably not continuous on the surface. Shafts in tuff-breccia in the angles between this mass and the phonolite of the summit show that both are cutting up through the first-named at steep angles.

On the ridge to the southward is a body of trachytic phonolite, crossed by the Midland Terminal Railroad line. This rock is fresh and coarser grained than usual in parts of this mass. In places it carries tablets of orthoclase half an inch long, making the porphyritic structure quite pronounced. Near the north end of this body it comes in contact with the nepheline-syenite mass, and two narrow offshoots of the latter cut across as represented by the map. Yet southwest of these dikes, where the main masses come in contact, the trachytic phonolite has its usual dense contact zones. As the nepheline-syenite also shows contact phenomena here, it is probable that the dense zone of the trachytic phonolite is that of its original contact with tuff-breccia and that the syenite here cuts directly on the older boundary line.

Nepheline-syenite.—The eastern part of the only mass of this rock found in the district is on the ridge above the Legal Tender mine, where, as above stated, it comes in contact with and seems to be later

than the trachytic phonolite. The outcrop of this rock forms a little shoulder on the western side of the ridge, and here the rock is in very fresh condition. It seems like a hornblende-diorite of medium grain, but has a peculiar pearl-gray feldspathic matrix for the flat augite prisms, and contains nepheline in considerable amount, as shown in Chapter II.

Phonolite of the cliff proper.—As has been stated in Chapter II, on the rock formations, the rock of the summit of Bull Cliff is unlike any other of the district, and its relation to the neighboring normal phonolite is not definitely known. The rock is fine-grained, mottled by round dark spots in a gray mass, and has a characteristic rough fracture. The cliff is due to a rude columnar structure in the rock, which is most distinct on the north and east sides.

From the few observations made this variety of the Bull Cliff rock is thought to grade into more normal-appearing phonolite near the borders and to the southward; but, from the grounds assigned in describing the rock (pp. 30–31), further examination must be made before definite conclusions on this point can be reached.

The outline of the Bull Cliff mass would indicate that it was a broad dike, but the contacts are so much obscured that its relationships to the adjoining rocks are not clearly shown except in a few places. About 400 feet southwest of the Victor shaft an incline explores the contact of the phonolite. The contact plane here has a strike about northwest to southeast and a dip of 35° SW. The phonolite is dense and sheeted parallel to the contact. In the mass of the cliff above this incline the tabular jointing of the phonolite is not parallel to the contact, but is very irregular in course.

From the dense contact zone, where this phonolite approaches the trachytic phonolite on the western side, it is clear that the cliff rock is the later.

Normal phonolite dikes.—Besides the peculiar rock of the cliff there are several long, narrow dikes of phonolite which cut all other rocks of the hill except the cliff rock. These dikes correspond perfectly to the common ones of other parts of the district. They are seldom more than 15 or 20 feet wide, when the width can be seen. As a rule they are exposed on one wall only, and hence their exact thicknesses can not be determined. Only the best-known dikes are shown on the map. Others are here and there revealed by prospects, but their extent and in some cases even their courses could not be ascertained.

BULL HILL.

General description.—Bull Hill is the highest of the hills in the central volcanic area, reaching an altitude of more than 10,800 feet. From its central position and the number of productive mines on its slopes it has become the most widely known part of the district, although a part of its fame belongs to the eastern point, which has

been described as Bull Cliff. On the flat ridge between the summits is Altman, the highest mining settlement of the region and one of the highest in the State, at an elevation of 10,600 feet. Two years ago the slopes of Bull Hill were covered with a dense growth of aspens, interspersed with spruce, but this growth is fast disappearing.

The hill is geologically different from the others of the mining area on account of the prominence of granite, which rises to its summit on the west, and from the large mass of trachytic phonolite, in which occur the principal mines of its eastern slope. Breccia is subordinate in amount to these two rocks. There are numerous dikes of phonolite and of basalt all through the mountain, and on the eastern slope of Bluebird Ridge, which is treated as a part of the hill, lies the larger part of the nepheline-syenite mass already referred to. A small remnant of andesite occurs at the northern base.

Granite.—The eastern half of the granite island shown by the map in the center of the volcanic area belongs to the mass of Bull Hill. It is principally of coarse-grained rock, and forms many outcrops, more or less obscured by slide rock and timber growth. But the numerous prospects all over it leave no room for doubt as to the continuity and the outline of the mass, which must represent a rugged peak of granite once completely covered by loose volcanic tuff and breccia, and now partially exposed again by erosion.

As has been pointed out in the preceding chapter, this entire granite mass is shattered to such a degree that in many places it is practically a granite-breccia. This may be clearly seen in many of the prospect workings on Bull Hill, as, for example, in the Albany tunnel, which runs easterly for nearly 600 feet into the mass. There are numerous distinct fissures or fissure zones, but between these the rock is often irregularly brecciated. Two very much decomposed white dikes were crossed by the tunnel, but they were also dislocated and broken up, making a determination of their courses uncertain. One of them is very possibly the same as that found in the Horseshoe shaft at the northwest base of the hill, where the shattered granite is also displayed. In numerous openings on the west slope of the hill near the contact the brecciated granite is well shown. At the extreme head of Arequa Gulch the Mohawk Belle shaft [*] is sunk in granitic breccia, almost all of which is very porous by removal of quartz, mica, and some feldspar, but as andesitic breccia seems to separate this point from the main granite area the outline is drawn above this shaft. Probably the uneven granite surface has occasioned this irregularity. From the Amanda shaft [*] on the contact, at the forks of the road west of the summit, down to Squaw Gulch the line runs obliquely down a steep wooded slope, on which occasional tunnels or shafts on either side locate it approximately. On the north the Jeff Davis shaft is in granite, and just below the road various trenches and shallow pits determine the line quite closely.

Trachytic phonolite.—The largest body of massive rock in the district is that extending from near the northeastern base of Bull Hill over its entire eastern slope, and ending rather obscurely on the western slope of Bluebird Ridge. The northern two-thirds of this mass is quite well defined, with sufficient occurrences of fresh or partially altered rock to demonstrate the character of the whole; but the southern end is all very much decomposed and the exposures are inadequate for accurate mapping.

The fresh rock may be found just north of the Buena Vista mine; down in the woods near the Morning Star; underneath the town of Altman; at the Shertloff shaft, below the Zenobia; and in a ledge outcrop south of the Pikes Peak and north of the Orpha May No. 2. At all of these localities may be seen the transition from the dark rock to a bleached porphyry in which the nepheline, nosean, sodalite, and pyroxene can no longer be recognized. The porphyritic structure of this type is usually very plain, for its feldspars are much larger than those of the augite-andesite, and in this way the rock may ordinarily be identified, even in its bleached condition.

Toward the southern end of the body the rock is often more or less porous by removal of pyroxene or of feldspar crystals. It has also been impregnated by pyrite and this has afterwards been leached out, making a porous, more or less iron-stained mass, indentifiable only by its apparent continuity with the body of Bull Hill proper. No evidence that there is more than one body was found, but such may be the case.

The arm running off northwest from the Bluebird mine becomes a porphyry with very dense ground-mass and sharply defined feldspar crystals. The Nightingale shaft is [*] apparently on the contact. Exposures are very few on the slopes of Arequa Gulch, and it can not be definitely ascertained whether the similar strongly marked porphyries occurring at several places on the adjacent slopes of Raven Hill are direct offshoots from this mass or not.

As to the form of this mass in depth, it can only be said that the rock apparently occupies a very irregular fissure whose walls doubtless descend at steep angles. The forking of the body near the Buena Vista mine is clearly shown by the wedging out of the breccia arm, and the dip of the eastern dike is approximately shown by the workings on the Buena Vista vein.

The shaft house at this mine is directly over the southwest contact of the dike, which approaches at the surface to within a few feet of the incline shaft following the vein. As the vein dips southwest here at a general angle of about 70° and both walls are still in the dike at a depth of 225 feet, it is clear that the dike must also dip southwest and at an angle not much if any steeper than the vein. It may be somewhat shallower, however, in which case the vein is obliquely traversing the dike. The thickness of the latter at the surface is not accurately known, as no prospects had disclosed the farther wall at the time of visit, but it is probably not less than 300 feet.

Directly opposite the Buena Vista mine a shaft [*] on the Orphan Bell property is sunk on an east-and-west vein crossing the contact of the larger eruptive mass, which descends very steeply, for at least 80 feet, to the first level; but through dislocations apparently connected with the vein fissuring at this point, the primary relations of the rocks are somewhat complicated. The general outline of the breccia tongue between the phonolite arms is plain, through numerous prospect developments.

The phonolite mass north of Altman, and in a less degree in various other places, is traversed by several systems of fissures, which at their intersections, or even in the space between the fissures of one system, produce a brecciated condition of the phonolite difficult to distinguish from the earlier andesitic breccia where the rock is much altered; and it is therefore possible that there are other tongues of andesitic breccia on this slope of Bull Hill subdividing the trachytic phonolite body into several arms. All the breccia seen was judged to represent local shattering of the massive rock.

The western outline of the trachytic phonolite on Bull Hill comes apparently to a contact with granite near the summit, though the line here was not actually seen. From the curve of the contact on both north and south slopes it seems probable that the eruptive descends practically on the granite surface for some distance.

Andesitic breccia.—On the north slope of Bull Hill the zone of breccia and tuff between the granite and the trachytic phonolite is for the most part only partially decomposed and indurated. Its andesitic character is plain in many places, and down near the small patch of massive andesite it has a dark-purple color.

On the southern slope, however, from the summit down to Arequa Gulch, the breccia is in general so fine and even-grained, and so thoroughly bleached and indurated, that its fragmental character is greatly obscured. Especially along the road above the Wolftone mine the clastic structure is difficult to make out. Still, by examining the dumps of the various prospects and mines here the fragmental character of the prevailing rock is made clear. There are dikes of phonolite, and possibly some narrow arms of the trachytic phonolite, not sufficiently exposed for mapping.

On the southeastern slope of the hill the fine fragmental character of the tuff and breccia is more distinct than on the western side of the phonolite body, yet all is extremely decomposed. There is a narrow band of fine tuff-breccia, much indurated, between the trachytic phonolite and the nepheline-syenite.

Below the Pikes Peak mine the brecciated rock of several prospects seems like trachytic phonolite fractured in place, and there may be dikes here which have been brecciated on some of the numerous fissure zones of this vicinity.

Nepheline-syenite.—This rare rock, whose occurrence seems particularly suggestive of the site of the main volcanic vent, occupies the hollow east of the Bluebird mine and extends over to the Legal Tender ridge as described. The rock is more easily decomposed than most of its neighbors, and its boundaries are not closely determinable on account of soil and slide rock.

The freshest portion of the mass is near the Longfellow mine at Independence, the end of the little ridge at this point being formed by the dark rock of which the quantitative analysis was made (p. 45). The northern boundary, below Hull's camp, is entirely concealed by alluvial material, but westward a large number of pits locate the line to within a few feet. Near the contact the rock is a fine-grained porphyry for a few feet, and when bleached and more or less fractured its distinction from the fine indurated tuff is not easy. The western and southern boundaries are indicated approximately by several prospects. A narrow dike offshoot of porphyritic rock cuts the ridge on the south. At the June Bell shaft [*] a narrow phonolite dike cuts the nepheline-syenite.

Phonolite dikes.—The map represents several marked dikes, three of which cut the nepheline-syenite mass. These are of the usual width and character. Other dikes occur, but their courses were not determinable for a distance warranting representation on the map.

Basalt dikes.—In numerous places prospect shafts have revealed narrow dikes evidently belonging to the latest eruption of the volcano, the basalts, but they are commonly so extremely decomposed as to render nearer determination impossible. An exception is the dike of fresh feldspar-basalt which is found in openings on the Wilson claim, north of Altman. This dike runs east-northeast and is cut in the drifts of the Buena Vista mine, where it is about 10 feet wide. It also appears on the surface cutting the breccia, northwest of the Lee shaft. It may possibly be an extension of this dike, which is exposed by a pit below the Zenobia, where the rock is very badly decomposed.

At shafts on the Lucky Guss, Eagle, Lottie No. 2, and adjacent claims, narrow dikes of soft, dark-green material are encountered, seldom more than 3 or 4 feet wide, and not distinctly traceable beyond the workings. Some of these dike rocks have prominent prisms of decomposed augite, and these were probably basalts of the Wilson dike type, while others are finer-grained and without marked augite remains. These rocks are more probably nepheline-basalts, similar to the Elkton and Anna Lee dikes. Such dikes occur at the Ben Harrison and Trail mines, and there is clearly quite a complex of these narrow dikes on this slope of the Bluebird ridge, some of which are doubtless continuous with those of Battle Mountain and Raven Hill. The dikes near the Ben Harrison trend west of north as a rule, corresponding to the Moose and Anna Lee dikes.

RAVEN HILL.

General description.—Raven Hill differs from the others thus far described in detail in that its surface exhibits no large bodies of massive rock, being made up of tuff and breccia cut by numerous dikes of phonolite and basalt. A part of the breccia is phonolite-bearing, and nearly all is bleached. The northern slope of the hill is heavily wooded, but the others are bare, with almost countless pits and trenches exposing the underlying rock.

At the eastern base of the hill is what appears to be a small explosive vent of more recent age than much of the rock decomposition. At the southern base is the main granite contact line.

Breccia.—The fragmental rocks of Raven Hill are breccias or tuff-breccias of more uniform texture, and are more completely decomposed than in any of the hills thus far described. The rock is seldom a fine-grained tuff, and yet the size of fragments rarely exceeds 2 or 3 inches. In but few places is the andesitic nature of the chief constituents determinable, but on the ridge leading from the summit to Anaconda there is a small area of dark augite-andesite breccia, a little below the North Star [*] mine. At the southern base, east of the Elkton, dark-colored material is exposed in a few holes. Ordinarily the tuff-breccia is much kaolinized, with no trace of dark silicates, stained and often more or less porous in consequence of the removal of pyrite, which seems to have once impregnated the entire rock mass.

Phonolite is a constituent of the breccia from the summit down the eastern, southern, and western slopes nearly to the base of the hill. It is commonly white, but is recognizable by its schistose structure. Occasionally pieces may be found which are partially fresh, especially on the western slope.

Granite fragments are locally found in the breccia, almost invariably with quartz and mica wholly removed and the feldspars kaolinized. Fluorite crystals may be found in the cavities.

The only indication of organic remains in the fragmental rocks of the volcano was found at the Appie Ellen shaft [*] near the contact south of the Elkton mine. Here a rather coarse-grained, bleached tuff-breccia fragment contained a cavity caused by the decay of a stem of woody matter with root-like appendages at one end. This specimen was submitted to Mr. F. H. Knowlton, who pronounced it evidence of vegetable remains, although wholly undeterminable.

Massive andesite.—It has been stated above that there are no distinct large bodies of massive andesite exposed in Raven Hill, but there are indications that underneath the breccia of the northern part of the hill there may be some such masses. This is indicated by small exposures here and there which are not large enough or of fresh enough rock to allow satisfactory conclusions as to their real character. Thus, near the Eclipse No. 1, on the crest of the ridge leading to Bull Hill, a single

shallow pit is entirely in what is probably the augite-andesite seen to be older than the breccia in other places, although the rock is not fresh enough to make it certain that the types are identical. All about this pit is fragmental rock, but not far away, especially on the Blue Flag claim, the fragments of the breccia are quite clearly of the type found massive in the above-mentioned pit. These observations are supplemented by the fact that in the Ida May shaft, just under the summit of Raven Hill, the rock appears to become massive in depth, although it is so much decomposed that there may be some doubt upon this point.

Again, on the west slope of Raven Hill, below the Ingham mine, there is a body of rock brecciated in place, and so much decomposed that the original character can not be surely recognized as that of the augite-andesite. This mass is shown in openings on the Mattie D. [*] and Doctor claims. Another massive-appearing rock is shown on the northwest slope of the ridge below the Maria A. shaft. In all of these cases the evidence is at present insufficient to demonstrate that they are bodies of massive rock to be compared with those of Bull Cliff, but it is highly probable that such is the case. Should all or several of them belong to a single type, it is probable that they represent a large irregular mass lying on granite.

Phonolite dikes.—Many phonolite dikes with general trend north to south occur in Raven Hill and on all slopes. Those best exposed are represented upon the map, usually with much exaggeration as to thickness, which rarely exceeds 20 feet, and is often only a few feet. At the Raven mine a purplish phonolite dike is shown in the upper tunnel, where it is cut by the nepheline-basalt dike, and apparently by another phonolite of white color and more or less porous structure through removal of crystals of feldspar.

Phonolite dikes occur on the east slope and on the ridge toward Bull Hill, but excepting those near the Kentucky Belle shaft [*] and at the Ida May their courses are not shown well enough for mapping. Near the Rhinoceros shaft [*] branching dikes occur, one arm running quite near the Ingham-Chief vein. Other dikes are indicated on the lower slopes near the Dolly Varden [*].

Down on the west slope, cutting the ridge south of Squaw Gulch, are several dikes whose courses are determinable, and in which partially fresh rock may be found. These dikes are met in the workings of the Morning Glory [*], Morning Glory No. 2, Rose Maud [*], Alexander Marsh [*], and Camilla [*] claims.

The railroad cut (Florence and Cripple Creek Railroad) at Anaconda, in the end of the ridge from Raven Hill, is in a white and thoroughly brecciated phonolite body, which apparently extends southwest along the railroad-line for some distance, and it appears to be one of the dikes cutting the breccia. But on the little ridge above the railroad this mass seems to grade into breccia carrying more and more andesite, and as sharp contacts were not found it may be possible that this phonolite

body is a remnant of an old one which furnished material for the phonolite-bearing breccia, and is not contemporaneous with the other dikes near by which clearly cut that breccia.

Basalt dikes.—The dark dike of the Elkton and Raven mines is sufficiently fresh to allow its determination as a nepheline-basalt (see description, pp. 49–50). The same or a closely associated dike occurs in the Appie Ellen shaft near the granite contact, and this has been analyzed (see p. 50). At the Moose mine a similar rock has been mineralized and is mined as ore. It is too decomposed for exact determination. The same dike or a parallel one is explored in the Bertha B.[*], while another one occurs in the neighboring Kentucky Belle [*] shaft.

Further occurrences of similar dikes may be mentioned on the Amanda and Sheriff claims on the ridge northeast of the hill, near the Ida May, at the Gettysburg, and elsewhere, on all slopes of the hill. The rock exposed in an open cut by the Sheriff shaft has large pseudomorphs of pale-yellow serpentine-like material after olivine.

About 100 feet southwest of the Dolly Varden shaft-house a pit on the wooded slope discloses a small, very fresh feldspar-basalt, not seen elsewhere.

Recent volcanic vent.—Near and northeast of the Moose mine, and south of the Kentucky Belle [*], three prospect holes near together show a purplish fragmental material different from any seen elsewhere, and contrasting especially with the tuff and breccia all around in the freshness of both the phonolite and andesite fragments. These are small, 3 or 4 inches in diameter or less, rounded in form, and lie in a fine sand or gravel of similar material. The augite-andesite of one of these fragments is fresher than any other andesitic rock of the district, and is different in type from the one usually found in the breccia. The phonolite fragments are also fresh and of several varieties.

The lack of induration and the comparative freshness of this crumbling material, and its different composition from the adjacent tuff-breccia, suggest that there is here a very small explosive vent of a period later than the general decomposition which the main formation has undergone. There are no outcrops, and no decisive evidence in favor of such a view was obtained beyond what has been given, but some such explanation seems necessary for this peculiar occurrence.

GUYOT HILL.

General description.—The small hill west-southwest of Raven Hill, on the border of the volcanic area, is chiefly interesting for the contact line with granite which runs through it. It is otherwise made up of breccia, in part phonolitic, and cut by several phonolite dikes. The hill has been called Sugar Loaf and Little Baldy, but current usage gives it the much more distinctive name here adopted.

Breccia.—Adjoining Raven Hill and down the slope toward Anaconda there is much phonolite in the fine-grained breccia of this hill,

but over the main western part it consists of andesite, not very clearly determinable, it is true, but comparable only with the andesitic rocks elsewhere. Granitic débris becomes abundant in the breccia only within a few yards of the granite line.

The contact line with granite.—In the railroad cut of the Florence and Cripple Creek Railroad, where crossed by the wagon road on the north slope, one may study to very good advantage the character of the zone bordering the granite. On the granite rests about 25 feet of a fine-grained, dense tuff; then come several feet of a grit-like material, consisting largely of granite débris, and finally a breccia of small fragments, principally of bleached andesite. There is a rude bedding displayed here.

The granite is much fractured all around the hill in the vicinity of the contact. This is most marked on the southern slope, where the brecciation and alteration of the granite are so great that the precise location of the boundary of the essentially volcanic material is a matter of doubt.

A ledge of specially silicified granite-breccia extends down the ridge toward Beacon Hill, with opal, chalcedony, and quartz filling the interstices between fragments. The Engineer shaft on this slope is in this fractured material. Occasionally bleached fragments of igneous rock appear in the breccia west of the boundary as drawn upon the map, but these seem more likely to come from narrow dikes in the granite of this fractured zone than to indicate the extension of the volcanic breccia. The line is drawn where abundant igneous rock appears in the breccia.

From Guyot Hill to the little ridge south of the Elkton mine the line passes under alluvial material.

Phonolite dikes.—In the summit of Guyot Hill is a small dike of but partially decomposed phonolite. On the side toward Beacon Hill at least one small dike from the latter penetrates the granite nearly to the breccia line. Another dike is exposed on the eastern slope, on the Camilla claim, and there are several indicated by slides on the north slope.

GOLD HILL AND ADJACENT RIDGES.

General description.—Gold Hill proper and the ridge leading west from it are composed almost entirely of rather fine-grained and well-indurated breccia. The complexity of dikes and irregular masses of various rocks characterizing most of the hills thus far described does not extend farther north than the southern ridge of Gold Hill, in which the Anaconda mine is situated, and it is convenient to speak of this spur as Anaconda Ridge, although it is strictly a part of Gold Hill. Pl. VIII shows the end of Anaconda Ridge with the extensive open workings on the Anaconda claim.

In Anaconda Ridge there are several dikes of a type of andesite not fully comparable with any others of the district, and here also occurs

a considerable mass of syenite-porphyry, the only mass of this type identified. The breccia of Anaconda Ridge is in part phonolite-bearing, while no distinct admixture of this rock was observed in the fragmentals anywhere to the northward.

The main boundary of the volcanic breccia runs along the western slope of Gold Hill on a line which seems to indicate a very steep easterly dip for the granite surface under the breccia. By the appearance of the schist projection through the breccia on the ridge toward Globe Hill, and the granite island on the east, it is evident that the breccia of this northern part of the area fills in hollows of a very rugged granite and schist topography.

Breccia.—The fine-grained breccia of the upper part of Gold Hill and of the northern slope is usually bleached, well indurated, and often richly impregnated with minute particles of pyrite. Where this has been leached out there is the customary iron staining and porosity. On the ridge leading west from the summit, on the flat near the schist line, the rock of a few pits is soft, purplish tuff, only partially decomposed. This is almost the only place where direct indications of the andesitic character of the débris may now be found, except in the workings of some of the tunnels in the lower part of Anaconda Ridge. Granite and schist fragments are not abundant in the breccia of Gold Hill, but are likely to be encountered at any point.

On Anaconda Ridge the breccia is very fine grained in the upper part, and so indurated as to resemble a massive rock, especially in the angular blocks of weathering found adjacent to the upper part of the Anaconda vein. But on the south slope phonolite becomes abundant, with, at the same time, the appearance of several distinct structural types of andesite in fragments several inches in diameter. All of the breccia is much decomposed.

The granite contact line.—The cuttings of the Florence and Cripple Creek Railroad on the north side of Squaw Gulch from Anaconda westward show the fissured and in some places brecciated granite for several hundred yards from the contact, as has been specially described in another place (p. 64). The line of granite and volcanic breccia is exposed on a scraped surface just above the railroad. From this point the contact line runs directly up the ridge leading to the top of the granite point at the end of the ridge from Gold Hill. From its course here it is evident that the contact plane is nearly vertical for a short distance, and this suggests a fault, but with no confirmatory evidence that could be found.

From the end of the ridge the contact line runs nearly straight to the edge of Cripple Creek. A part of the way an inclusion of fibrolitic and micaceous schist comes in contact with the breccia.

The schist island.—The small patch of schist in the saddle between Gold and Globe hills is penetrated by several shafts, proving its continuity, but the boundary between the schist and breccia is not well

shown. In the Index claim a shaft [*] starting in schist cuts at 55 feet depth into a dike of very much decomposed diabase, in which the ophitic structure is still plain, and traverses it obliquely, passing through it at about 75 feet. Granitic veins occur in this schist mass, and one or two narrow white dikes of kaolinized eruptive also occur. The schist is rich in quartz and silvery mica, with variable amounts of fibrolite and feldspar. The rock is of the same general character as the schist of the north side of Poverty Gulch, with which it is possibly continuous under the breccia.

Syenite-porphyry.—The shoulder of Gold Hill to the southeast is caused by a mass of a rock not found elsewhere in the district and which may best be called syenite-porphyry. It is strictly porphyritic in structure, yet its feldspar and augite crystals are small, and the ground-mass is unusually coarse-grained (see p. 45), so that one naturally associates this rock with the nepheline-syenite as products of consolidation under somewhat different conditions from those of the other larger bodies. From the various local characteristics of the formations in Anaconda Ridge it has been suggested (pp. 62, 66) that there may have been at this point a second or lateral vent of eruption, and the syenite-porphyry may represent the conduit of this center.

The rock is fresher than most of the types of the region, although minute dusty interpositions in the feldspars cause it to appear dull. It forms outcrops all over the ridge, and descends to within about 100 feet of the gulch opposite the Dolly Varden mine.

On the western border of this mass a prospect shows a dioritic rock which has been regarded as a local phase of the syenite-porphyry, but the relationships of the two are not exposed. Near the top of the ridge a shaft explores the contact, proving the porphyry to cut the breccia. Generally the contact is concealed by slide rock.

Dike rocks.—The breccia of Anaconda Ridge is cut by several dikes, the only determinable ones being of an andesite containing augite, mica, and hornblende. It is shown in freshest condition in the main Anaconda tunnel, near the entrance. The brown fragments of this distinctly porphyritic rock cover much surface near the line of the tunnel, but the probabilities are that there are but two or three dikes, cutting diagonally across the ridge, and furnishing much slide rock for the slope below. From the irregular contacts of the two dikes cut by the Anaconda tunnel it is difficult to connect them closely with the surface bodies, which are still less distinctly outlined.

On the western slope of the ridge a dike of this same andesite, 4 or 5 feet wide, has been cut by several tunnels and shafts, and other dikes are shown by single openings in the ravine north of Anaconda, and on its western bank near the town.

A narrow dike (2 or 3 feet) runs parallel to the Anaconda vein through all the upper workings, but now it is only possible to say that it had a fine porphyritic structure, and was not markedly schistose

parallel to the walls; hence it may more plausibly be referred to andesite than to phonolite.

Recognizable phonolite dikes are rare in Gold Hill, though here and there proved by slide rock or single prospects. They are probably narrower and shorter than in the other parts of the district, and hence have not been so well exposed in the present development. One narrow one is shown in the Florence and Cripple Creek Railroad cut at Anaconda, close to the contact line, and some of those cutting the ridge south of Squaw Gulch doubtless continue into the adjacent slope of Anaconda Ridge. A few very narrow dikes occur in Gold Hill proper.

The dike represented on the map as crossing the contact on the ridge southwest of Gold Hill is almost unique in the district. It is really a quartz-porphyry, with many small orthoclase crystals, and with quartz only in the ground-mass, but could not be given a special color on the map. From the evidence of the shafts and tunnels which cut this narrow dike it is clear that it has been dislocated and locally shattered, so as to form a breccia itself, as at the shaft in the pass crossed by the trail from Cripple Creek to Anaconda. It is one of the rare cases observed where a dike actually crosses the main contact from breccia into granite.

GLOBE AND IRONCLAD HILLS.

General description.—As regards igneous materials, the two hills of this section, and the ridges leading out from them, are more exclusively composed of tuff and breccia than any other part of the mining region. Granite forms the southern half of Ironclad Hill, belonging to the isolated body referred to in describing Bull Hill, while an irregularity of the contact line brings the granite nearly to a connection with this island on the eastern slope.

There are doubtless some dikes in the area, but none were seen that could be mapped.

Breccia.—The same variety of fine-grained breccia, highly indurated, which occurs in Gold Hill forms the western ridges from Globe Hill, and on Ironclad Hill it is especially white and hard, with granite débris not uncommon. Nowhere is the dark color due to its andesitic origin to be found, but in Globe Hill, in and adjacent to the Summit and Deerhorn mines, the fine-grained tuff has been rendered loose and crumbly and is stained various colors—yellow, red, brown, or purple—as a result of an action more recent than the common induration and impregnation with pyrite. These dark shades must not be confounded with those primarily due to the andesite, as on Bull Cliff.

On the pass north of Globe Hill, and down to the granite line, there is often a marked silicification of the breccia. Much granite is locally contained in the breccia near the contact.

Granite.—The granite of Ironclad Hill is very much fractured and decomposed, as on the adjacent slope of Bull Hill. It is abundantly exposed in the Wichita, Londonderry, and other claims. The course of

the contact line is defined by numerous shafts and tunnels on either side, but none have followed the contact far enough to show the detailed character of the contact plane for more than a few feet.

POVERTY GULCH AND TENDERFOOT HILL.

Breccia.—The northern limit of the continuous volcanic breccia formation of the central area is at the pass between Tenderfoot and Carbonate hills.[1] Near the summit of Tenderfoot Hill some prospects have disclosed breccia with dark-colored fragments, in which the andesitic character is still partially preserved, but over the greater part of the southern slope and in the gulch the rock is very completely altered, although the fragmental character of the mass is usually plain. The breccia is often fine-grained, white, with pyrite particles abundantly sprinkled through it. Granite is often recognizable as a constituent, though always subordinate.

The contact line with schist and granite.—The upper line of the breccia from the pass west of the hill can be easily traced over the summit down into the north fork of Poverty Gulch and then back again to the divide at the head of Grassy Gulch. For a part of the distance a silvery mica-schist with large folia of mica bounds the breccia, as shown by the map.

On the west is also an area, predominantly at least, of schist; but decomposition, taking the form of extreme kaolinization, has so bleached and altered both schist and breccia as to make the distinction of one from the other all along this line a matter of close examination at every step. The contact is doubtless less regular in minor detail than is represented. Crossing the ridge west of the Gold King mine the schist contains larger mica flakes than usual and the line is sharply defined. The schists are locally injected with many granitic veins, which, by their complete kaolinization, aid in obscuring the relationships.

The mouth of the Chicago and Cripple Creek tunnel in Poverty Gulch is in schist, almost on the contact with breccia, into which the tunnel quickly passes. South of the C. O. D. mine, in the south bank of the small branch of Poverty Gulch, the Rebecca tunnel, after passing through about 75 feet of breccia, crosses a vertical fault plane running nearly northwest, beyond which schist is encountered for nearly 30 feet; then a second apparent fault, nearly parallel to the first, brings in a very white massive rock, probably phonolite, into which the tunnel had penetrated but a few feet at the time of visit. The massive body is in all probability a dike.

From the present depth of the C. O. D. shaft (300+ feet) it is plain that the schist surface to the westward must dip very steeply, but such

[1] Much confusion exists both in general usage and on claim maps in the application of these names, but the prevalent tendency seems to be in accord with the use in this report and accompanying map, whereby the name Tenderfoot is given to the hill north of Poverty Gulch and Carbonate to that west of the stage-road pass.

faulting as that displayed in the Rebecca tunnel may greatly complicate the relations of granite, schist, and breccia in this area.

Andesitic dikes.—The only dikes of prominence in this part of the district are of andesite. One of them cuts along the slope just above the Gold King tunnel and is encountered in the workings of that mine, as described by Mr. Penrose (pp. 173–174). The other dike, of the same rock type, is found on the south side of Poverty Gulch near its head. It is shown only by a few prospects, and the representation of the map is doubtless incorrect as regards width and length.

GRASSY CREEK.

The granite boundary line.—The irregularities of the line between granite and tuff or breccia on the slopes of Grassy Creek [1] are such as to most clearly show that the tuffs, etc., rest upon a very uneven surface. At the extreme head of the gulch alluvial material obscures the contact, so that it is uncertain whether the tuff remnant on the hill east of Tenderfoot Hill has been entirely separated from the main area or not. The tuff of that hill is in part dark-colored and rests on a southerly dipping surface. At the east end of the top of the hill the granite near the contact is shown to be very porous through the usual decomposition.

On the south side of the creek the granite arm which runs up almost to a surface connection with the isolated body of Bull and Ironclad hills is fairly well outlined by prospect holes and a few outcrops, in spite of the unusually heavy timber growth on this slope; but the line of the map representing the tuff as crossing the creek is not well exposed. Its course must be approximately as indicated, however.

Phonolite hill opposite Bull Cliff.—The body of phonolite on the north side of Grassy Creek is apparently a sheet dipping southward very nearly on the contact between tuff and granite. An encircling ledge outcrop bounds it about the northern or upper half, and although talus conceals all contacts the prospect shafts on the east and west, below the ledge, expose loose purplish or gray tuff, seeming to represent a thin layer between phonolite and granite. This tuff layer thins out upward and seems to be absent at the northern edge, but it may run around this side of the phonolite as a very narrow band, entirely covered by débris.

The phonolite of this mass is very dense and fresh, breaking across the usual fissile structure with a conchoidal fracture.

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[1] In the earlier days of the camp the valley north of Bull Hill was frequently called Gassy Creek, and that name was used on the Pikes Peak atlas sheet, but current usage is almost entirely in favor of Grassy, and hence this name is here adopted.

CHAPTER V.

THE DISTRICT ABOUT THE VOLCANIC CENTER.

GENERAL SKETCH.

Area to be considered.—The broader geological features of the general region in which the Cripple Creek volcano lies have been treated in the introductory chapter of this report. It is the intention to present in this place some further details regarding the portions of the district covered by the map but not described in the preceding chapter, and also references to certain outlying localities where formations connected with the volcanic center have been found. The Pikes Peak atlas sheet shows the position of these localities relative to the Cripple Creek district.

Features to be described.—Granite and gneiss, with the various schist masses included in them, occupy the greater part of the surface about the center, as a glance at the map will show. Except for the decomposition adjacent to the volcano these formations present nothing in this area which is peculiar to it. The same is true of the diabase dikes which occur here and there throughout this portion of the Colorado Range and have nothing to do with the later eruptions of the volcano.

Of the formations belonging strictly to the volcanic center, there are but two remnants of the tuff and breccia of any considerable size, while dikes and masses of phonolite of unknown original form are so numerous that it would seem as if a greater amount of this magma had been injected into these peripheral fissures than had issued from the central vent. This distribution of phonolite is one of the most noteworthy features of the district.

In Grouse Mountain are remnants of a rhyolite flow in all probability not connected in origin with the Cripple Creek volcano. Associated with this rhyolite are certain grits or sandstones, and from the occurrence of phonolite in the same mountain some evidence may be adduced as to the relationship between the volcanic period of the western area, referred to in Chapter I, and the volcanic period of Cripple Creek.

AREAS OF GRANITE AND GNEISS.

Distribution of granitic types.—The characteristics of the leading varieties of granite have been given in the petrographical chapter (pp. 20–23). The coarser-grained Pikes Peak type is the most prominent, occupying all the area north, east, and south of the volcanic center and extending for miles beyond the map boundaries. It is to be understood that finer-grained granite occurs in dikes, and that comparatively small

masses of various types may occur, but the "country rock" of all is the Pikes Peak type.

On the west of the stream of Cripple Creek and south of the divide running west from Mineral Hill is an area occupied principally by the Cripple Creek type, as it has been called. This is somewhat finer grained, richer in biotite, and thus darker in color than the other, and is somewhat variable in appearance. Schist fragments are very numerous in this granite.

Fine-grained, reddish granite dikes cut both of the main types. Coarse pegmatitic veins are found here and there, but are by no means so numerous as in many other parts of the Colorado Range, as, for instance, on the eastern slopes of Pikes Peak; and the type of vein carrying large crystals of amazon stone, smoky quartz, and other minerals, which have made the Peak so famous, is entirely lacking. White quartz veins with subordinate amounts of feldspar are rare. The greatest development of pegmatite and quartz veins seems to be in Squaw Mountain.

Gneiss.—A development of gneiss from the granite as a result of a shearing movement in certain zones is to be observed in a few localities within the area of the map, as, for example, in the railroad cuts on the southern slope of Squaw Mountain. The clearest evidence upon this point is to be found in the canyons of Eight-Mile Creek, a few miles south of Victor, or on the Colorado Springs road near Middle Beaver Creek. In these localities the change from coarse-grained granite to a finely schistose gneiss may sometimes be traced within a few feet, the transition from large, sharply defined feldspar crystals to the flat lenses or "augen" of the gneiss being very distinct.

In the hilly country adjacent to the volcanic center the granite and gneiss are not often well exposed, and the relations of gneiss and granite must be inferred. In the western part certain patches of fine, even-grained gneiss, rich in biotite, are more plausibly to be considered as inclusions in granite, like the schists, than as derivatives of the granite.

No attempt was made to work out the details of the intricate associations of granite and gneiss in this district, for the reason that the investigation of the phenomena of the immediate mining district required all the available time, and the problems of these older formations can be studied to much better advantage elsewhere.

Sheeting of granite and gneiss.—A marked sheeting of granite and gneiss by numerous parallel fissures, which are usually vertical or dip at steep angles, is quite prominent in many parts of the district and far beyond its borders. The prevalent trend of these fissures is somewhat west of north, but certain systems run east of north. There is undoubtedly an intimate connection between these fissures and the ore-bearing veins of the mining district, as is pointed out by Mr. Penrose (pp. 139 et seq.).

By the sheeting of the granite and the consequent influence on erosion, sheer walls several hundred feet in height and very rugged pinnacled ridges are caused in some of the deeper canyons. Pls. III and IV illustrate the prominence of this sheeting of granite and the resulting forms shown in the canyon of Eight Mile Creek on the railroad line. Other localities where this feature is distinct are on the southwestern side of Pikes Peak between the forks of Beaver Creek, and at "The Crags," on the northwestern slope of the Peak.

That this fissuring is later than the volcanic rocks is clear in many places, notably in the railroad cut west of Victor, where the loose tuffs and agglomerate of the minor vent in granite are seen to be traversed by the same fissures which cut the granite.

Disintegration of granite.—The Pikes Peak granite is specially subject to surface disintegration through agencies of weathering. This is most pronounced in the Peak proper, where many slopes are entirely covered by gravel of this origin. To some extent the same cause has produced the smooth slopes of the Cripple Creek region, and as these surfaces are very often covered by a dense aspen growth the granite is effectually concealed until exposed by prospect shafts or local erosion.

The wooded ridges north of the volcanic area and west of Trachyte Mountain are of this character.

Diabase dikes.—The narrow dikes of this ancient igneous rock occur here and there all over the district. The rock is generally decomposed, and seldom causes distinct outcrops except in the rougher, canyon country.

Near the town of Cripple Creek, to the northwest, several diabase dikes occur, and a number of pits have been sunk in them. They are not so regular in width as the phonolite dikes, and their representation upon the map, except where well exposed, is necessarily inaccurate.

In and around Brind Mountain a number of diabase dikes were found by Mr. Mathews, only a few of which could be traced sufficiently for representation. The long one on the western slope may be somewhat broken in its continuity.

SCHIST INCLUSIONS IN GRANITE.

General character.—The small areas which have been mapped as schist and referred to as inclusions in granite are not always clearly of this character as exposed in this region. But, as stated in the introductory chapter, the examination of the adjoining district on the west has proved beyond question that the various granite types there found contain an enormous number of distinct fragments of stratified quartzites and allied quartz-mica-fibrolite-schists detached from some source as yet unknown. These fragments are large and small, and in the canyon of Oil Creek and the side canyons, only a few miles southwest of Grouse Mountain, there are literally hundreds of these fragments to be seen sharply defined in normal granite.

Not all the fragments of the western area are distinctly derived from quartzites, and many of them contain so much mica, fibrolite, and even feldspar that some of them must be assumed to be altered gneisses and may represent the Archean, on which the old quartzites were laid down.

In the Cripple Creek district no inclusions of pure quartzite are found, and most of the rocks appear to have been derived from gneisses. As a rule, the schist bodies near the volcanic area are white, with much silvery muscovite-mica, a great deal of quartz, and some feldspar or kaolin replacing it. Fibrolite is common, but not always distinguishable to the naked eye. Biotite also appears locally.

Distribution.—The largest schist area of the region is that between Mineral Hill and the main breccia. It is almost indistinguishable from the white kaolinized breccia until closely examined. Dikes and narrow impregnation veins of granite occur in it, but are similarly decomposed. The schist becomes very distinct in its character on the ridge north of Poverty Gulch, as seen at the Chicago tunnel, in the island projecting through the breccia between Globe and Gold hills, and adjoining the breccia west of Gold Hill.

On the north bank of Grassy Gulch are several dark and somewhat fresher schistose rocks, which carry fibrolite very distinctly, with biotite and feldspar, a part of which is microcline. The quartz grains carry magnetite particles.

The other schist masses distinguished upon the map are for the most part quite distinct quartzitic mica-schists, but some are fine-grained gneisses that are believed to be related to the schists. Their outlines as given are often not accurate in detail, owing to the imperfect exposures.

VOLCANIC BRECCIA.

Mineral Hill.—North of the town of Cripple Creek a mass of very much altered breccia and tuff, like that in Tenderfoot Hill, extends up the slope of Mineral Hill, forms its summit, and is traceable down the northern side almost to Spring Creek. It can be regarded only as the filling of a north-and-south depression in granite and schist. The view of Pl. I shows the southern slope with its smooth, grassy surface penetrated by many shallow prospect pits. The northern slope is heavily wooded and exposures are rare.

The pits of the southern slope are seldom deep enough to more than show the underlying breccia; but near the western edge of the mass a number of them do penetrate granite under the breccia, showing the latter to be a thin, irregular layer. As much might be inferred from the course of the boundary.

On the summit of Mineral Hill, on the eastern side especially, the material is largely made up of a granite gravel, and weathered fragments look very much like a coarse granite.

Lodes Roaring Brook

It is possible that a fault limits the breccia on the northeast side of the summit, for a shaft almost on the boundary penetrates dark, purplish tuff for probably 50 feet—the shaft was inaccessible—and proves a very steeply dipping granite wall in any case. On the northern slope of the hill the outline can be only approximately located in the timber by occasional outcrops of granite and by a few prospects. Down near the gulch granite outcrops below the breccia, and a tunnel (Puzzler?) running south shows breccia resting on an uneven granite surface.

The western shoulder of Mineral Hill is caused by a small mass of andesite resting on breccia. It is not so much altered as the breccia, but has been impregnated with pyrite, and several shafts have been sunk on fissures in it.

The reservoir at Cripple Creek is excavated in a fragmental material which is probably not directly equivalent to the breccia, although given the same color on the map. As far as exposed at the time the excavation was made, the chief constituent was granite in subangular and rounded blocks, with others of andesite, much decomposed, and also fragments of breccia. A rude bedding appeared through thin layers of purplish tuff, and the whole seemed to be rearranged material, quite different from the very dark normal andesitic breccia resting on granite at the southern end of the main Mineral Hill body, 100 yards or so to the northwest. The reservoir mixture seems most probably to be a remnant of a local lake-bed deposit of very limited extent.

Rhyolite Mountain.—The fragmental volcanic formation of Rhyolite Mountain is exposed in shafts and tunnels and in poor exposures on the southern slopes. Phonolitic débris from the summit mass is more prominent than tuff over the western side, but shallow pits serve to reveal the tuff below. In several places on the southern slope and in the Parkview shaft, which is sunk in breccia close to the phonolite ledge on the northwest side of the top, the andesitic character of the fragments in the breccia is still plain. It is not bedded, so far as observed, and rests upon a surface of granite dipping northwest.

On a western spur of the mountain, dignified unduly by the name Knob Mountain, a thin remnant of tuff was found by Mr. Mathews, seeming to underlie the phonolite of that point.

Other traces of volcanic tuff.—It would certainly be remarkable if there were not several smaller remnants of the tuffs belonging to the Cripple Creek volcano in the adjacent country to the north and east, where erosion has been less marked than to the westward. But if such remnants exist, it is thought that they must be small, filling hollows in the granite surface. As a heavy aspen growth covers much of the region, their detection is perhaps to be accomplished only by the prospector. A specially favorable place would seem to be under the phonolite sheet of Cow Mountain, some 2 miles northeast of Bull Cliff.

A small remnant of dark tuff and breccia occurs on Mount Pisgah, which lies just beyond the line coinciding with the western border of

the map area, opposite Cripple Creek town. It probably underlies the phonolite capping of the mountain, but the smooth, grassy or aspen-covered slopes of the conical summit have been too little explored as yet to determine this point.

On the plateau about Little Pisgah Peak, south of Grouse Mountain, are remnants of dark-red tuff, which will be referred to in describing the formations of Grouse Mountain and vicinity.

PHONOLITE.

Areal distribution.—Phonolite is the only one of the rocks connected with the Cripple Creek volcano possessing any noteworthy distribution beyond the limits of the central area already described. But its occurrence is so widespread, and in some respects so peculiar, as to deserve special attention.

The accompanying map shows numerous narrow dikes and several larger masses of phonolite on all sides about the breccia. A reference to the Pikes Peak atlas sheet will show that masses corresponding to the larger ones of the Cripple Creek district were found at the following points: (1) On an unnamed hill nearly 2 miles north of Trachyte Mountain; (2) on a ridge near the Midland Terminal Railroad, 2 miles north of the map line; (3) on Cow Mountain, 1 mile southeast of Trachyte Mountain; (4 and 5) in two masses on Middle Beaver Creek, 4 miles east of Trachyte Mountain; (6) on the southern slope of Pikes Peak, at an elevation of 11,500 feet; (7) capping Little Pisgah Peak, 1 mile south of Grouse Mountain; (8) at Nipple Mountain, 4 miles east of south from Straub Mountain; (9) at Mitre Peak, 3 miles south-southwest of Grouse Mountain; (10) in a hill on the west side of Oil Creek Canyon, 4 miles west-northwest of Grouse Mountain; (11) capping Mount Pisgah, just beyond the western border of the map, opposite Cripple Creek.

Narrow dikes of phonolite were also occasionally found during the survey of the Pikes Peak area, and at distances of several miles on all sides.

Characteristics of the larger phonolite masses.—The larger number of the more important phonolite bodies form the summits of rather sharp-pointed hills, and then extend down the slope, in some cases for a long distance, as though the viscous magma had issued from a vent at the summit and flowed as a lava-stream down one side. But as the hills are otherwise of granite and the phonolite in no case has the structural features of a surface flow, this impression is speedily shown to be incorrect, and a nearer examination of some occurrences explains most of the observed masses.

The masses studied in some detail are of three types. First, the inclined dikes in granite, such as those near Cripple Creek; second, the masses injected laterally into the High Park lake-beds, as in Grouse and Straub mountains; third, irregular necks in granite, illustrated by

one shown in the cliffs of the south fork of Wilson Creek south of Straub Mountain.

Compared with these typical occurrences it seems very probable that the masses of Big Bull Mountain, the two hills north of it, and the hill north of Grassy Creek, are lateral injections of phonolite into fissures which on reaching the surface of granite upon which the fragmental materials of the volcano had accumulated were deflected to a general parallelism with that surface. Such an origin brings these bodies practically into the category with the Grouse Mountain mass.

It must be assumed from the observed facts that at some time in the history of the volcano there existed a considerable mountain mass, largely of fragmental materials—in short, a volcanic cone—and that it covered a somewhat larger area than that of the present map. If the larger phonolite bodies of the region belong to one period of eruption, while the volcanic cone was at its maximum size, it is quite natural that many of the fissures should branch out at the base of the mountain, following the various local inclinations of the granite surface. This is especially plausible because there is a strong tendency manifest in certain dike fissures in granite to become flatter in their dips near the old surface.

Of the masses which may be explained in this way, that of Little Pisgah is probably similar to the Grouse Mountain body, as will be more fully explained in describing the High Park beds. The small masses of Rhyolite and Knob mountains, by their shape and relation to tuffs, seem very possibly of this origin, although narrow dikes of different character are also present. The cap of Mount Pisgah (10,405 feet), whose perfect conical form is shown in Pl. II, is composed of phonolite for several hundred feet, descending lower on the eastern than on the western slope; and from the discovery of andesitic breccia on the southern side near the phonolite it seems not impossible that the phonolite is a lateral injection near the granite line, and it might have come from the fissure in granite west of Cripple Creek.

No tuff was observed on Trachyte Mountain, and talus débris obscures the contacts; but Mr. Mathews, who traced the outlines of the phonolite body, is inclined to believe that there are local necks or channels of eruption at this point.

The phonolite body of Cow Mountain extends from the summit to the southern base, a distance of 1 mile, and in relation to the granite strongly suggests the idea of a flow from the summit; but it is in all probability an inclined dike in granite, all the granite above the portion seen having been eroded away. Such seems also the only interpretation for the inclined masses of Beaver Creek and Pikes Peak.

Narrow dikes of phonolite.—As phonolite is known to have had several periods of eruption in the volcano, it is but natural to suppose that the dike occurrences in granite about the center may also belong to different periods, and the contrast in form between the nearly vertical

dikes, usually of narrow width, and the larger inclined masses treated above, may in general distinguish at least two periods.

The narrow dikes shown upon the map often do not exceed 15 feet in width, but may reach a thickness of 100 feet or more. An accurate representation of these upon a map of the scale of the present one is impossible, even if the width could be determined. But as a rule only the more important and clearly exposed dikes are shown by the map, and the exaggeration is not more than is necessary to make them distinct.

No pronounced system is visible in the arrangement of the dikes, which may be due to inability to distinguish dikes of different periods. A rude radiate structure appears in the relation of the dikes on the south of the center, but no kind of system is distinguishable on other sides.

That there are certain systems of connected fissures is clear from the branching of the dikes between Grouse and Squaw mountains, and again south of Battle Mountain. Those in the area north of the center display no regularity whatever.

Many of these little phonolite dikes have more or less porous zones adjoining them, arising from the decomposition of the granite in the manner frequently referred to in preceding chapters. This seldom extends more than a few inches from the dike and is plainly a contact phenomenon.

The dike rock is very dense adjoining the granite and is invariably schistose parallel to the walls. Fresh or but partially decomposed rock is shown by many prospects and in some outcrops, but commonly the dike matter is white and schistose.

These dikes are so much alike over the entire area that no local descriptions seem necessary.

Inclined dikes west of Cripple Creek.—West of the valley of Cripple Creek are four gently inclined dikes of phonolite which deserve some special mention. They have very irregular, tortuous courses, which are partially due to changes in dip and strike, but more largely to the topography. There seems to be a certain radiation as the general strike changes from southwest to northwest.

The thickest but shortest is that west of the town of Cripple Creek, in Cemetery Hill, and the connected higher point south of it. This body covers much of the eastern slope, but is sharply limited on the west by a well-exposed contact running along the edge of the cliff or abrupt face. Shafts and tunnels on this line, which has a notable contact zone of porous granite, show the contact to descend very steeply a few feet and then flatten out to something corresponding to the apparent inclination of the mass. The southern arm of this mass forms a sharp east-west ridge with a cliff of granite on the south. The rock of this mass is fresh in a few places and contains large porphyritic crystals of nepheline. Its thickness must be more than 100 feet, but from

the irregularity of the only contact well exposed it can not be closely estimated.

The next dike southward is narrower, but longer than the first. It can be continuously traced, except for the bottom of Cripple Creek, from the head of Pony Creek to Squaw Gulch. The changes in strike and dip are many, but on the whole the strike is northwest and the dip somewhat more than 50° northeasterly or northerly. The width is about 100 feet on the ridge west of Cripple Creek and considerably less on the east, decreasing to a few feet at the Squaw Gulch end. There is the usual porous granite contact zone at many places, and near the eastern end some ore deposition in this zone, as at the Caledonia mine.

The most clearly defined of these dikes is the one ending at Mound City in a manner obscured by the bottom alluvium of the creek. This dike has a general east-west strike and exhibits many outcrops of fresh rock as well as very marked porous contact zones in granite, which are opened up by many prospects. In the cavities dark-purple fluorspar is often abundant. The dip is variably steep to the northward.

The longest and thinnest of these dikes extends from Beacon Hill southwesterly for more than 2 miles, following the general course of Cripple Creek. The dike is seldom more than 30 feet thick and has a dip in northwesterly direction, which is usually between 30° and 45° where it could be estimated. It may be that this dike is also present on the middle slope of Grouse Mountain, where a few indications of phonolite were found on the heavily wooded surface. This dike is usually decomposed.

PHONOLITE OF BEACON HILL.

The large mass.—The map shows the upper part of Beacon Hill to consist of a large body of phonolite. Its contact is not well exposed by natural outcrops, but mines and prospects reveal it at several places, and their evidence tends to show that this phonolite body is an irregular intrusion in granite expanding near the present surface. Nearly all contacts dip into the hill. Thus, at the Little May, on the western side, a shaft shows the contact with granite dipping 70° into the hill; on the southwest a shallow pit exposes phonolite on granite with a small northeasterly dip for a few feet at least; at the northeastern extremity a tunnel shows a nearly vertical contact.

The rock is the usual dull-green, rather dense phonolite, becoming denser near the contact, and the adjoining granite has suffered the usual alteration, losing its mica and part of its quartz. This may be seen in the Little May shaft very clearly.

Phonolite dikes.—Near the Prince Albert and Gold Dollar mines several narrow phonolite dikes seem to branch off from the main mass and extend some distance into the surrounding granite. The actual junction of dikes and main body was not observed at any point, but just

west of the Prince Albert shaft, and only a few yards from the apparent line of the larger body, a network of bleached dikes in granite was seen, and one of them, at least, probably connects with the main mass at this place. The details at this point can not be represented with the scale of the accompanying map.

The dikes which run down the slope toward Arequa are well exposed. On the west no direct connection could be found between the dikes shown upon the map and the central body. In this particular the Pikes Peak atlas sheet is probably incorrect in representing a dike connecting with the large mass of the hill.

GROUSE MOUNTAIN.

The mass of Grouse Mountain, near the southwestern corner of the district, is of special importance on account of its large phonolite body and the relations of that body to the older formations, the rhyolite and the grits of the High Park lake. These relations have already been discussed while describing the grits, in Chapter II, and also in connection with the question as to the age of the Cripple Creek volcano.

The large phonolite body.—The principal rock of the upper part of the mountain is phonolite, of the coarse-grained porphyritic variety, carrying many reddish crystals of nepheline. This is the largest phonolite mass of the district, and the one of all the large bodies whose manner of occurrence is most distinctly shown. At the southern end of the mountain it is 450 feet thick vertically, and its length is nearly 2 miles, decreasing in thickness toward the northeast.

From its relations to the grits and rhyolite, stated below, this body appears to be a lateral injection into the grits, and it is not certain that the magma came from any of the small dikes on the east, although they seem at first probably connected in origin with the large mass. It is more probable, on the whole, that the Grouse Mountain phonolite came up through some such fissure as that of the inclined dike west of Mound City, or from the same channel as the similar mass of Straub Mountain.

On the southwestern slope a lower sheet-like dike cuts up obliquely nearly on the line between rhyolite and grit. Its lower contact with rhyolite, near the north end of this body, dips 40° northeast, as shown in an incline which explores it. There is a marked sheeting in this body from the fissile structure parallel to this contact plane.

In general the main phonolite mass is bleached, but ordinarily the structure is plain, and often fresh rock with very distinct nepheline crystals may be found. On the north slope the timber growth and talus material obscure the contact, but the line was located closely at several points by outcrops or prospect holes in solid rock.

The narrow dikes of phonolite.—The map shows a number of long, narrow, curving and branching phonolite dikes on the ridge between Grouse and Squaw mountains. These dikes have the usual porous

contact zones in the adjacent granite, and have been exposed by numerous prospects, sunk either on one of these contact zones or where some fissure crosses the dike and zone. The representation of the map is doubtless somewhat inaccurate in detail, as the dikes are often concealed by soil or slide rock, but the character of the dike fissure system is correctly shown. Some of these dikes come very near to the main mass at its northeastern extremity, but were not actually traced to a connection.

Between Grouse and Straub mountains an inclined dike was traced in its irregular course to within a few yards of the large body, and is shown on the map as connecting with it. It may, nevertheless, belong to a different period of eruption.

Rhyolite and High Park grits.—On the western and southern slopes of Grouse Mountain the main phonolite body is found in contact with the rudely bedded grits, composed largely of quartz and reddish feldspar, or small particles of granite, which have been correlated with the Miocene High Park lake-beds on grounds discussed at length in Chapter II. The crumbling beds are well shown only in prospect holes, especially on the ridge leading southward across the boundary of the map to Little Pisgah Peak. The thickness of the grits is greatest at the south end of the mountain, where more than 100 feet of the beds is surely present.

The grits rest on granite, or locally on rhyolite, as shown by the map. The rhyolite is very variable in thickness, from erosion prior to the deposition of the grits, and is found in subangular blocks in the grits where they rest upon it. The thickness of the rhyolite is difficult to estimate because the slope of the granite surface on which it rests as a flow is unknown, but somewhat more than 100 feet of it would seem to be preserved on the southwestern slope of the mountain.

The general level of the ridge running south from Grouse Mountain represents an old floor of granite, once covered by rhyolite and the overlying grits, which extended south and west for an unknown distance. To-day this old floor can be traced, through the grits and the underlying rhyolite, from Grouse Mountain southward for more than a mile, forming a bench around the northern and western sides of the phonolitic cone of Little Pisgah Peak and ending in the rampart projections from this peak, which face the deep canyons of Cripple, Oil, and Wilson creeks. In Chapter II was given a discussion of the evidence indicating that a north-south fault of about 1,000 feet runs at the western base of Little Pisgah, by which the region embracing the Cripple Creek district has been elevated, and that the rhyolite and overlying beds of High Park, on the west of the fault, were once continuous with the formations of Grouse Mountain.

The injection of phonolite.—On the summit of Grouse Mountain is a patch of rhyolite with a remnant of grits upon it, as outlined upon the map. Around the edge of the rhyolite prospect shafts have passed

through it into phonolite at varying depths less than 40 feet. Near the triangulation station another patch of rhyolite appears on the top of the mountain. At the extreme north end of this is a small area of grit, but the prospect shafts do not clearly show its shape, and the surface is of loose material. Both of these patches are interpreted as irregular detached fragments borne on the upper surface of the phonolite.

This interpretation is sustained by the isolated outcrops of rhyolite or of grit found below the phonolite on the eastern side of the mountain, as shown by the map. On the ridge southeast of the triangulation station is a very distinct outcrop of rhyolite, which thins out to the north and ends abruptly on the south. There may be a thin grit remnant between this rhyolite and the phonolite, as fragments were found in the slide, but no outcrop was found. In the gulch opposite the center of the mountain a thin rhyolite sheet occurs below the phonolite, and a little farther south is the end of the grit outcrop, resting on granite.

At the northeastern extremity of the mountain the relations are complicated and obscure in spite of numerous prospects. The drawing of the map is intended to express the idea that the phonolite body is rapidly wedging out to the northeast and, with a steep southerly dip, is cutting up through a thin rhyolite remnant and a very little of the grit. It may be that the phonolite is here passing by a steepening dip into one of the narrow dikes with northeasterly course. There are possibly places on the northwest slope where other outcrops of rhyolite or grit should be shown between phonolite and granite, but no evidence of them could be found. The grit material of all these isolated portions of the formation is usually indurated, and often at the same time rendered porous by removal of quartz and other particles, and thus comes to resemble the similarly affected granite of contact zones or of detached fragments. As the grit is essentially granitic gravel this resemblance is, under the conditions, quite natural.

The conclusion from these facts is that the phonolite body seen is an intrusion into the High Park grits, and the natural implication is that there must have been a considerable thickness of these sediments at the time of intrusion. This is proved by the development of the formation in Straub Mountain. And it is also to be remembered that the tuffs and breccias of the Cripple Creek volcano undoubtedly covered this area at one time. Direct evidence of this extension is found in shafts on the western side of Little Pisgah Peak, close to the phonolite body. These shafts penetrate tuff and purplish breccia very similar to the finest-grained material found on Big Bull Mountain. Down the slope to the westward the grits and rhyolite are found at lower levels, and apparently there may be 100 feet or more of tuff resting on the grits at this point. At the Dowling claims on the bench northwest of Little Pisgah red volcanic mud or tuff rests on grit and rhyolite, but the relationships are complicated by small faults.

STRAUB MOUNTAIN.

The High Park beds.—The rudely stratified grits or coarse arkose sandstones which surround the phonolite bodies of Straub Mountain and the flat ridge south of it have been exposed in a goodly number of prospect pits, else their character would be very difficult of determination. In constitution they are like those of Grouse Mountain, with less of the hard quartzite pebbles, and no rhyolite has been observed under them or contained as fragments in them.

The beds continue south of the map line only a half mile, to the edge of the deep canyon of a south branch of Wilson Creek. They rest on a granite surface which dips gently westward, and the thickness of the beds is probably between 200 and 300 feet.

Near the phonolite masses the grit is hardened, and weathered fragments of this indurated material, such as are abundant on the eastern slope of the mountain, are at first sight much like a coarse granite. No andesitic matter has been observed in the grits, and no further evidence was obtained bearing on the question as to whether the granitic débris came from the Cripple Creek volcano or not.

Phonolite.—Beside the three phonolite masses shown by the map there are two others on the ridge just south of the map line and one in the cliffs of the south fork of Wilson Canyon. This last body is a neck of roundish outline clearly cutting up through the granite. The rocks are dense, as a rule, but in parts of the mass of Straub Mountain proper the rock is a fine-grained porphyry from development of nepheline, as in Grouse Mountain.

A fissile structure is very marked near the southern end of the largest mass, the plates being thin and variously inclined in different places.

Relation of phonolite and grit.—Slide rock conceals the contacts almost everywhere, but several shafts less than 30 feet deep sink through grit into phonolite near the road between the largest and smallest bodies of the mountain. The contacts prove the phonolite an intrusion into the grits, as on Grouse Mountain. But the boundaries of the phonolite are very irregular, as might be expected from the loose, gravelly character of the grit formation into which the magma was intruded.

At the south end of the largest mass a shaft on the west side of the ridge goes down on an east-west fracture plane, filled with soft gouge matter, the fracture decreasing in its steep northerly dip as depth is gained, with phonolite on the north (or hanging) and grit on the south (or foot) wall. This is apparently a small fault plane, whose course would carry it directly across the south part of the surface phonolite body, and, judging from outcrops near by, the dislocation can not be very great.

CRIPPLE CREEK FROM THE EAST.

Mount Pisgah in the background.

MINING GEOLOGY OF THE CRIPPLE CREEK DISTRICT, COLORADO.

By R. A. F. Penrose, Jr.

INTRODUCTION.

The work on the mining geology of the Cripple Creek district, including the examination of all the mines then accessible, was finished early in November, 1894, so that the discussions and descriptions given in this report are all based on the facts then available, and the extent of development in the various mines is given as it existed at that time. Since then many of the mines have been sunk deeper and explored more extensively, and many new mines have been opened. In spite of the fact, therefore, that the present report is published only a few months after the district was examined, many facts have since been discovered which can not be embodied herein. Such occurrences must inevitably happen during the preparation of a report on any mining district, but especially a new one like Cripple Creek, which is the scene of remarkably active development and where there is an unasually large number of producing mines. The main statements made in this report, however, would probably be but little, if at all, modified by recent developments, though they might be somewhat expanded.

The writer takes much pleasure in acknowledging the uniform courtesy and assistance extended to him in the somewhat laborious work of examining the many mines of the district, by the various mine owners and by the people of Cripple Creek and other towns, without which the investigation could not have been carried on in so short a time and so completely as it has been. To Messrs. Tutt & Penrose, mining brokers, especial thanks are due for a great deal of assistance, which was made possible by their extensive knowledge of the district and their willingness to give all aid possible, often at the expense of much time and labor. To Messrs. Luckraft & Countryman, C. J. Moore, Thomas L. Darbey, Lloyd & Rigney, E. Skewes, and other mine surveyors and

mining engineers, many thanks are due for information and cooperation that could not have been otherwise obtained. To Messrs. P. E. C. Burk, Joseph Troy, F. T. Freeland, N. W. Burdick, Bela Kadish, E. M. De La Vergne, James Doyle, J. C. Staats, James Murray, and others the writer is indebted for many courtesies and much assistance. To Mr. N. E. Guyot he is especially indebted for many of the historical facts relating to the district.

CHAPTER I.

HISTORY OF MINING AT CRIPPLE CREEK.

LOCATION OF THE DISTRICT.

The discovery of valuable deposits of gold ore in the Cripple Creek district was not made in an unexplored or inaccessible region which had heretofore escaped investigation, but it was made in a part of the State which had been well known to both miners and ranchmen for many years. The district is in El Paso County, 30 miles west of Colorado Springs and 75 miles south of Denver, just west of the Pikes Peak Range, and in full view of the Sangre de Cristo Range, still farther west. It covers an area of 6 miles in length by 5½ miles in width, in the high, rolling, grass-covered country intervening between the two main ranges of the Rocky Mountains in Colorado, and lies southeast of the upland valley country known as South Park. It has long been a favorite region for the ranchman, while it has more than once come to the notice of the miner.

EARLY DISCOVERIES IN THE DISTRICT.

The recent discoveries in the district were made at a time when the increasing depression in the value of silver had begun to be seriously felt among the producers of that metal in Colorado, and it was the first in the series of notable gold discoveries in the Rocky Mountains which have lately been brought about, directly or indirectly, by the fact that mining men were anxious to find a more profitable field for their operations than silver mining. Previously, however, several unsuccessful attempts had been made to develop gold resources in this region, as well as in the surrounding country.

The Pikes Peak gold excitement in 1859 and the collapse of that boom occurred many years before gold was known in the Cripple Creek region. At that time thousands of people flocked westward by ox teams and mule teams and were disappointed in their search, yet only a few miles farther west lay what is now the Cripple Creek district; but it was for a later generation that this discovery was reserved. While the Pikes Peak excitement developed but little of value in that immediate locality, it had the effect of bringing people into the country, and after the collapse of the boom many of them scattered through the mountains and were the early explorers of some of the mining districts which have since become famous. The region

of Cripple Creek, however, with its smooth, grass-covered hills, did not appear to them so promising a field for exploration as the more mountainous regions surrounding it, and it was passed by as unworthy of notice except by the ranchman.

Long after the Pikes Peak episode, and yet about twenty years before the present developments at Cripple Creek, gold was accidentally discovered in the region where this district is now located, and it was the cause of two mining excitements previous to the last one; but, unlike the last one, they both quickly died out, for no paying mines were discovered. It is stated that during the work of the United States Geological and Geographical Survey under Hayden in this region some specimens of gold ore were found by H. T. Wood, who was connected with the Survey. At that time the discovery attracted no special attention, but some years later, in 1874, Wood came to Colorado Springs and called the attention of some of the citizens of that town to his discovery made several years before. From his description of the place in which he had found the specimens, they recognized at once that the region was the one now known as the Cripple Creek district, and a prospecting party, accompanied by Wood, immediately started out to make further investigations. Some loose fragments of ore ("float") were discovered on the surface, and on the 13th of August, 1874, a mining district was organized under the name of the Mount Pisgah district.

The news of the discovery of gold spread rapidly, and the usual rush of prospectors, miners, and speculators took place. A number of shafts and tunnels were opened, but the rich ore bodies discovered later on by the more fortunate prospectors of the present Cripple Creek were not encountered. Stimulated, however, by the occasional discovery of rich "float" on the surface, the quest was continued for several years; and even as late as 1878 one Henry Cocking opened up a tunnel in what was later known as Poverty Gulch, near where the Gold King and C. O. D. mines are now operated. Gradually, however, the continued lack of success discouraged the prospectors, and the district was finally abandoned. Many of the old openings of this period can still be seen, and among them is a shaft near the Eclipse mine, made by B. F. Requa,[1] of Colorado Springs. From this and many other old workings it is evident that the unsuccessful explorers of 1874 were in the very heart of the Cripple Creek district.

The second mining excitement in this district was in 1884, and was started by the alleged discovery of fabulously rich gold deposits west of Mount Pisgah. The discovery was said to have been made by one S. J. Bradley, more commonly known as "Chicken Bill," who located a claim under the name of the Teller Placer on April 5, 1884. People at first believed that the long-looked-for gold of the old

[1] The present name, Arequa Gulch, on the south side of Raven Hill, is a corruption of Requa Gulch, which was named after the above-mentioned Mr. Requa.

Mount Pisgah district had at last been discovered, and again the stream of miners and prospectors turned into the region, in even greater numbers than in 1874. Five thousand people were soon on the spot, and for the second time active prospecting was started. Before long, however, it was observed that gold could be found only on Chicken Bill's claim, and it was later discovered that he had put gold there himself—"salted" the claim, as it is called—in the hope of selling out to some unsuspecting stranger. Chicken Bill fled to escape being lynched by the infuriated people, and the district was rapidly deserted.

Thus up to 1884 this region had undergone two periods of mining excitement, the first caused by an honest but unsuccessful search for ore, the second caused by an effort to perpetrate a mining swindle; and yet it is remarkable that during all this exploration not a single one of the really valuable ore bodies which are being worked to-day was discovered. This is probably due largely to the fact that the ore was different in appearance from that with which the prospectors of that time were familiar, and also to the fact that a heavy covering of soil and loose rock obscured most of the outcrops of the veins.

RECENT DISCOVERIES IN THE DISTRICT.

The first to discover valuable bodies of gold ore in the Cripple Creek district was Robert Womack, who owned a ranch in that region, and who, led on by his frequent discovery of fragments of rich ore, continued his search for the source of these pieces until, in the fall of 1890, he found ore in place, and located the El Paso claim, on which the Gold King mine in Poverty Gulch is situated. He took some specimens of the ore to Colorado Springs the same year, and on the strength of these, in the winter of 1891, E. C. Frisbee and E. M. De La Vergne went into the region, making their headquarters at the Broken Box ranch of George W. Carr, near the site of the present town of Cripple Creek, and prospected with signal success. They were the first who really opened and developed valuable mines in the district. The first regularly paying mine was the Gold King, in Poverty Gulch, which was opened by Frisbee on the El Paso claim, and from which ore was shipped in November, 1891. Other discoveries followed, and shortly after the opening of the Gold King, De La Vergne opened the Raven mine. Both of these mines prospered, and are to-day among the most prominent in the district.

GROWTH OF THE DISTRICT.

Thus successfully started, the region began to develop. In the spring of 1892 the rush began, and for the third time people streamed in. New mines were rapidly opened, and the different parts of the district were explored in quick succession. The Gold King, Raven, Lone Star, Rose Maud, Buena Vista, Victor, Mary McKinney, Anaconda, Morning Glory, Independence, and others were among the mines early to become

prominent, and before many months had elapsed encouraging developments had been made on all the noted hills—Bull Hill, Globe Hill, Gold Hill, Raven Hill, Beacon Hill, and Battle Mountain—as well as in Poverty, Squaw, and Arequa gulches. The record, however, of two previous attempts to find gold, added to the now notorious rascality involved in the Chicken Bill episode, made many people skeptical as to the real value of the discoveries. Especially was this true of mining men and capitalists, who were inclined to look on the district as one which had been thoroughly explored and proved worthless, so that, consequently, the early operations were carried on largely by men who were classed by the "old-timers" as "tenderfeet." or. because many of them came from ranches, as "alfalfa miners."

No one fact retarded the development of the district more than this lack of confidence, and as a result operations were conducted on very small capital. To the credit of the district it should in fact be said that, with only a few exceptions, all of the paying mines have been developed almost entirely on the profit from the ore extracted during development, with little or no other capital to pay the many expenses incident to opening new mines. The developments of the years 1892 and 1893 were so encouraging, however, that even the more incredulous began to relax, capital turned toward the district, and the remarkable progress made in the latter part of 1893 and in 1894, in spite of the many local difficulties, is sufficient proof of the active work that has gone on.

In the fall of 1894 the number of mines and more or less developed claims at which mining operations were being conducted amounted to over 100, among the most prominent of which were the Victor, Buena Vista, Pharmacist, Burns, Zenobia, Pikes Peak, Morning Star, Grouse, Orpha May, Specimen, Blue Bird, and others on Bull Hill; the Summit and Deerhorn on Globe Hill; the Gold King and C. O. D. in Poverty Gulch; the Anaconda, Great View, Excelsior, Lone Star No. 2, City View, and Gold King on Gold Hill; the Raven, Moose, Bertha B., Elkton, Catherine, Jack G., Ingham, Gregory, Ida May, North Star, Chief, Mary McKinney, Republic, Dolly Varden, Mountain Monarch, and others on Raven Hill; the Caledonia in Squaw Gulch, and the El Rino or Sweat near Mound City; the Prince Albert, Gold Dollar, and Beacon on Beacon Hill; the Independence, Portland, Strong, Granite, Anna Lee, and others on Battle Mountain.

GROWTH OF CRIPPLE CREEK AND NEIGHBORING SETTLEMENTS.

When Frisbee and De La Vergne first came into the district, in 1891, the only habitations were a few scattered ranches, notably the Broken Box ranch of George W. Carr; but when the influx of people began the next year three towns rapidly came into existence—Cripple Creek, Fremont, and Barry. The first two were adjoining settlements at the headwaters of the stream of Cripple Creek, and as they grew and

blended together, they were united as one town under the name of Cripple Creek. The town of Barry was started less than 2 miles southeast of Cripple Creek, in Squaw Gulch, and is now known as Anaconda, on account of the proximity of the Anaconda mines. The name of Cripple Creek is taken from the stream of that name, on which the town is situated, but its origin is doubtful. Some say that several accidents occurred almost at one time in the family of a ranchman living near by, and hence the name of the creek. The usual story for the origin of the name, however, is that a cowboy in "rounding up" cattle on the creek ran afoul of a steer, and the steer, horse, and rider fell, breaking the rider's arm, the horse's leg, and the steer's neck.

From the isolated Broken Box ranch in 1891, the settlement of Cripple Creek has increased at an astonishing rate to a flourishing incorporated town of some 10,000 people in 1894, with a splendid water supply from the foothills of Pikes Peak, electric lights, telegraph and telephone lines, daily papers, and various other facilities and comforts of a modern town. Like most Rocky Mountain towns which are supported by mining industries, however, Cripple Creek is still called a "mining camp," for it is impossible for such towns, no matter what size or city-like character they may develop, to outgrow this appellation.

Previous to the advent of the railroads, the town was reached by stage lines running in several directions, the most important of which were the routes from Cripple Creek to Florence, to Canyon City, to Divide, to Florissant, and to Colorado Springs. In the later days of staging, however, the only routes that were actively maintained were those to Canyon City (30 miles), Divide (17 miles), and to Colorado Springs (30 miles). In 1893 two railways were started into the district, and in 1894 they both reached there, so that it is now supplied with two competing lines of transportation. One of these roads, a branch of the Colorado Midland, starts from the station known as Divide, on the main line of that road, runs south to the town of Gillette, and thence over a very circuitous course to Victor, from which town it is being built to Cripple Creek. The other road, known as the Florence and Cripple Creek Railroad, starts from the town of Florence, on the Denver and Rio Grande Railroad, runs north through a very rugged region to Victor, and thence to Cripple Creek.

Outside of Cripple Creek numerous smaller settlements and towns have sprung up, which are the result of the local requirements of the miners in different parts of the district. Among the most important of them are: Victor, Gillette, Anaconda (formerly Barry), Mound City, Arequa, Lawrence, Altman, Hulls Camp, Independence, and Goldfield, all of which are included in an area 5 miles long by 3 miles wide. The total population of the Cripple Creek district, including not only the town of Cripple Creek, but all the surrounding towns and settlements within the boundaries of the district, is estimated at about 15,000.

PRODUCTION.

In the Cripple Creek district, as in all other gold districts, accurate figures concerning the production of gold are difficult to obtain on account of the many outlets for the ores and placer gold. A certain amount of information can usually be obtained from the returns of the smelters and mills, but figures from these sources are often unsatisfactory because, especially with the smelters, there is frequently some doubt as to the exact localities from which certain shipments of ores have come. The number of tons of ore produced can be accurately determined from the reports of the railroads which carry it and the reports of mills to which ore is hauled in wagons; but the amount of gold in these ores is much more difficult to learn. This is especially true of the gold obtained from the placer deposits, which is often carried off and not recorded by those who mine it, so that only a very general estimate of its true value can be made.

The first gold in the district was produced in the latter part of 1891, and in that year the output amounted to only a few thousand dollars. In 1892, 1893, and 1894 the production steadily increased, and at the beginning of 1895 the monthly output was still increasing. According to the returns of the United States mint at Denver, kindly furnished by Colonel Puckett, assayer in charge, the total production from 1891 to 1894, inclusive, was $5,543,967, while, according to figures derived from various local sources at Cripple Creek and Colorado Springs, the total production during the same time was a little over $7,000,000. It may be added here that, in any conservative estimate of the production of a gold district like Cripple Creek, there is more probability of the statistics of production being too low than too high, for, as just stated, a considerable quantity of gold is always taken out of the district without being recorded.

SUMMARY.

The statements in this chapter may be summarized as follows:

The ore deposits of the Cripple Creek district were discovered in a well-known part of Colorado, and at a time when silver mining was beginning to be a less profitable industry than previously.

Two attempts, both unsuccessful, had been made to find gold in the district before the recent discoveries.

The developments in the last three years, in spite of adverse conditions, have been remarkably successful, and the town of Cripple Creek and numerous outlying settlements are the result of this success.

The gold production of the district from 1891 to 1894, inclusive, has been estimated at $5,543,967 by the mint of the United States at Denver, and at over $7,000,000 by various local authorities.

CHAPTER II.

THE ORES.

GENERAL FEATURES.

The ores of the Cripple Creek district are almost exclusively gold ores. A little silver generally occurs in most of them, and in a few cases its quantity is sufficient to be of importance, but as a rule it is small. No other metals occur in any of the ores in quantities of commercial value. The ores consist usually of country rock, more or less impregnated with and replaced by quartz and other minerals, among which the most abundant are fluorite, opaline silica, and kaolin, with iron pyrites and other iron minerals, manganese oxides, and, more rarely, small quantities of galena, cerussite, anglesite, malachite, acanthite, tetrahedrite, stibnite, sphalerite, calaverite, native gold, oxidized tellurium minerals, gypsum, calcite, and numerous other minerals in still smaller quantities. The stibnite, the sphalerite, and the copper minerals, including tetrahedrite, are very rare.

The ores differ from those of many other gold districts in often, though not always, consisting simply of country rock, either eruptive materials or granite, containing more or less secondary quartz and associated minerals; while in most gold districts, and in fact in parts of the Cripple Creek district, the ore consists of well-defined bodies of these materials. A characteristic ore of the district is an intimately mixed mass of quartz and purple fluorite, prominent from its brilliant purple color. The gold occurs in the ore as free gold, as telluride of gold, and possibly as auriferous iron pyrites, the last being the least important form. These various conditions of gold, as well as the associated materials, will be described separately.

FREE GOLD.

The gold in the placer deposits and a part of that in the veins is in the form of free gold. In the veins the free gold usually predominates in the upper parts of the ore bodies; but within a depth of 100 feet, and in some cases much less, the telluride of gold, associated with more or less iron pyrites, usually appears and gradually takes the place of the free gold. Though such is the general experience in the district, yet a few mines have been sunk several hundred feet on ore carrying gold in its free state. In such cases, however, it is noticeable that the vein minerals are in a very thoroughly oxidized condition, and it is probable that the presence of free gold at a greater depth in certain mines than in others is largely due to the fact that the

oxidation of the telluride and iron pyrites in these mines has extended to greater depths than usual.

The superficial mode of occurrence of the free gold, and its replacement by the telluride and iron pyrites below, point clearly to its having been derived largely, if not altogether, from the oxidation of one or both of these materials. Its physical and chemical condition also corroborates this view and seems to point to its derivation mostly from the telluride, and possibly to a lesser extent from auriferous iron pyrites, though, as will be shown later, it has not yet been definitely proved that the latter plays much part as a source of gold.

The free gold frequently occurs in thin, angular plates or sheets, which are brittle and porous, like gold obtained by dissolving other metals from a gold alloy. The plates often show a marked striation similar to that seen on the faces of crystals of the unaltered telluride, and in fact their angular form seems to represent the crystalline form of the telluride, of which they seem to be pseudomorphs.

The gold occurs in both a coarse and a fine condition, sometimes in particles so small as to be invisible to the naked eye, and at other times in plates or spongy masses from an eighth to a quarter of an inch in diameter. It is rarely clean and bright, and is generally coated with a thin, rusty film of a yellowish-brown ferruginous compound, which, when tested chemically, often shows the presence of tellurium in an oxidized form. This material may be one of those indistinct oxidized compounds of iron and tellurium which are known to occur where tellurides and iron pyrites have been oxidized together; or it may be simply a hydrous oxide or a basic sulphate of iron containing this tellurium and iron compound, or some other oxidized tellurium compound, as a mechanical admixture. The fact that the telluride ores are almost always mixed with more or less iron pyrites would explain the presence of iron in either case. This subject is more fully discussed under the head of the superficial alteration of the ores, but it may be added here that the open, porous condition of the gold renders it especially fit for the absorption of this rusty coating. The free gold of both the placer deposits and the veins, when separated from its rusty coating, is often remarkably pure, sometimes not even containing any appreciable quantity of silver, as will also be more fully discussed under the heading of the superficial alteration of the ores. The most striking exception to this usual purity is seen in some of the ore from a locality on the hill above the Rose Bud mill, which sometimes contains over 40 per cent of silver.[1]

The above facts leave no doubt that a large part of the gold of the district is derived by oxidation from the telluride, for such a supposition explains the angular shape of the pieces of gold, their striation,

[1] A few other mines in the district produce ore containing considerable silver as well as gold, but in these cases the gold and silver are not usually in the entirely free state, such as described above, but are in association with galena, sphalerite, or other minerals, to be mentioned under the head of Silver Minerals.

their porosity (which might readily be produced by the removal of tellurium), the presence of oxidized tellurium materials in the rusty coating of the gold, and many other features. In further support of this supposition it may be said that some of the free gold in Boulder County, Colo., and elsewhere, is supposed by Pearce[1] to have been derived in a similar manner. Some of the free gold in the Cripple Creek district, however, may possibly have been derived from auriferous iron pyrites, though the amount attributable to this source is doubtful (see below); and possibly a part of it has been in the free state since it was originally deposited.

TELLURIDES OF GOLD.

Though gold in the form of telluride is abundant throughout the district, it is only rarely that it occurs in a state of sufficient purity to afford specimens for satisfactory quantitative analysis. In three of the mines, however—the C. O. D., the Raven, and the Prince Albert—such specimens were obtained. These have been analyzed by Dr. Hillebrand, of the United States Geological Survey, and have been determined by him to be calaverite. His report is given at the end of this chapter. Dr. S. L. Penfield, of Yale University, has kindly made an examination of the crystalline form of the same calaverite from the C. O. D. and Prince Albert mines that was analyzed by Dr. Hillebrand, but the crystals were too much striated and too imperfect to give satisfactory measurements, as will be seen by his statement given at the end of this chapter.

It is not impossible that other tellurides of gold besides calaverite, such as krennerite, sylvanite, hessite, petzite, and others, may also occur at Cripple Creek, but the fact that three specimens from widely separated parts of the district have proved to be calaverite is suggestive of the general distribution of this mineral. Additional evidence of this is had in the fact that F. C. Knight[2] has also found what he supposes to be calaverite in an impure specimen from this district. Richard Pearce,[3] however, who was the first to describe the ores of Cripple Creek, supposes the telluride in ores examined by him from the Garfield Grouse, the Moose, and other mines to be in the form of sylvanite.

Selenium in very small quantities in specimens of ore has been reported by F. C. Knight,[2] of Denver, and by J. D. Hawkins, of Cripple Creek.

AURIFEROUS IRON PYRITES AND OTHER IRON MINERALS.

The close relation of the quantity of gold to the quantity of iron in a few cases at first suggests that auriferous iron pyrites is a source of some of the gold. This relation, however, is seen in only a very few veins, and the rich ore bodies are usually independent of the iron,

[1] Proc. Colo. Sci. Soc., Vol. II, Jan. 7, 1885, pp. 1-6.
[2] Ibid., Oct. 1, 1894.
[3] Ibid., Jan. 8 and April 5, 1894.

sometimes containing considerable quantities of it, sometimes containing very little. Samples of ore carrying large quantities of iron pyrites or oxidized iron minerals often contain large quantities of gold, but iron pyrites and telluride of gold are often so intimately associated in this district that it is possible that some of the gold which appears to be dependent on the iron may be in the telluride form, or may have been in that form before it was oxidized. In many gold ores, not only in this district but elsewhere, the abundance of iron pyrites and other sulphides often leads to the belief that all the gold occurred originally in these minerals; but a careful test will often show the presence of more or less tellurium, and it is not improbable that some of the gold, both in the Cripple Creek district and elsewhere, heretofore supposed to be in the sulphides may have been partly also in the form of telluride closely associated with sulphides. Pearce[1] has shown such an occurrence in the ores of Breckenridge, Leadville, and other places in the Rocky Mountains.

That some of the iron pyrites in the Cripple Creek district contains no gold is shown by the fact that two pure crystallized specimens examined by Dr. Hillebrand contained not a trace of it; but this does not necessarily indicate that the same mineral from other places might not carry it, and in fact it is very possible that it does. Investigations on this subject have not yet been pursued further, for in the cases where the mines had gone deep enough to reach entirely unaltered sulphides at the time the district was examined, it was difficult to get the material in a perfectly pure state, and unless it is perfectly pure there is always a possibility that some of the gold in it may be in the telluride form intimately admixed with the iron pyrites.

Iron pyrites is common in both the veins and the country rock. In the country rock it occurs in small, disseminated crystals, but in the veins it is more plentiful, though even here it is not so abundant as in many gold districts. Sometimes, though rarely, it occurs as more or less continuous bodies in the veins, but more commonly it is in small, scattered crystals, and not infrequently it is disseminated through the ore in a state of extremely fine subdivision.

Where the iron pyrites has been oxidized in the upper parts of the veins the iron has usually been converted largely into its oxidation products, the hydrous or anhydrous sesquioxides, the basic sulphate, and other forms. Limonite and hematite both occur, the latter in only very small quantities, and Pearce[2] has shown the presence of a basic sulphate of iron, possibly the mineral glockerite, which is known to be formed under similar circumstances elsewhere. A specimen of ore from the Raven mine has been shown by Dr. Hillebrand to contain a phosphate of iron; and a specimen of a soft, light-yellow material from the Ida May mine on Raven Hill has been shown by him to be a

[1] Proc. Colo. Sci. Soc., 1890, Vol. III, Pt. III, p. 257.
[2] Ibid., April 5, 1894.

hydrated ferric silicate, perhaps a variety of chloropal. The following analysis by Dr. Hillebrand shows its composition:

Analysis of chloropal from the Ida May mine.

	Per cent.
Silica (SiO_2)	41.80
Ferric oxide (Fe_2O_3)	37.[illegible]0
Water (H_2O)	19.90
Lime (CaO), etc	1.10
	100.00

The material also contains a trace of phosphoric acid and perhaps a little alumina.

MANGANESE MINERALS.

Manganese is very generally distributed in small quantities in the ores of the district, occurring usually as a black stain, or as films lining cracks in the ore. Occasionally, though rarely, it occurs in larger quantities, and forms nodules and irregular masses in the ore, notably in the Summit and the Pharmacist mines. It is sometimes hard and massive, probably representing the mineral psilomelane, while elsewhere it is soft and pulverulent, probably representing wad, or else a mixture of oxides.

The occurrence of these oxidized manganese minerals in the joints and cracks of ore bodies suggests their derivation from the oxidation of other manganese minerals. The manganese may have been originally in the form of one or both of its sulphides, and the occurrence of alabandite with the telluride gold ores of Nagyag, Kapnik, and Offenbanya, in Transylvania, is suggestive in this direction; but the sulphides of manganese are rare minerals, and even in Transylvania the alabandite is associated with the carbonate of manganese; so that it seems probable that, though the manganese oxides now found in the Cripple Creek district may have been derived partly from sulphides, their principal sources were the carbonate (rhodochrosite) or the silicate (rhodonite). In support of this supposition it may be said that the oxidized manganese minerals in the silver deposits of Butte City, Mont., pass into these minerals at a depth, while in the Ontario mine, at Park City, Utah, at some of the mines at Idaho Springs, Colo., at Pinos Altos, N. Mex., and at a number of other places in the Rocky Mountains and the arid regions, manganese oxides pass into one or both of these minerals at a depth, and so far as yet discovered in these places there is no evidence that the carbonate and silicate of manganese have been derived from sulphides. In fact, all their surroundings suggest that they are in the condition in which they were originally deposited.

SILVER MINERALS.

Small amounts of silver occur in many of the gold ores of the district, especially in those which are unaltered, but in only very few is it in considerable quantities. The most prominent of the mines producing silver-bearing gold ores are the Blue Bird, Wilson, Blue Bell, and a locality on the hill back of the Rose Bud mill. The mineralogical condition of the silver in the Blue Bird is somewhat doubtful. The ore contains free gold, telluride of gold, iron pyrites, a little stibnite, and probably small quantities of other sulphides, so that it is possible for the silver to occur in several different ways. The following assays, kindly furnished by Dr. N. W. Burdick, owner of the mine, show the percentages of silver carried in the ore:

Analyses of ores from the Blue Bird mine.

	1.	2.	3.	4.
Gold (ounces per ton)	20.60	0.40	28.60	70.80
Silver (ounces per ton)	70.40	1.60	251.00	204.20

The silver of the Wilson mine, which is on Bull Hill, near Altman, is in the form of an antimonial tetrahedrite, carrying considerable silver. An approximate analysis by Dr. Hillebrand gave 11.19 per cent of silver, 18.70 per cent of antimony, 28 per cent of copper, and about one-half per cent of gold, which, however, is probably mechanically admixed.

The silver of the Blue Bell mine, in Squaw Gulch, occurs in a mixture of galena and sphalerite, and the following analysis, kindly furnished by the manager, Mr. J. S. Lentz, shows its composition:

Analysis of ore from the Blue Bell mine.

	Ounces per ton.	Per cent.
Gold	0.60	
Silver	62.50	
Lead		8.50
Zinc		18.30
Iron		2.80
Silica		45.00
Water		1.15

The silver in the ore in a locality on the hill above the Rose Bud mill, so far as yet discovered, occurs as an alloy with native gold, though at a depth it may possibly go into some other form. The amount of silver varies from only a few per cent up to almost half the alloy.

LEAD MINERALS.

Lead occurs in a number of places in the district, but is almost always in very small quantities. So far as known it is either in the form of galena or of the carbonate (cerussite) and rarely of the sulphate

(anglesite) derived from the galena, and it usually carries silver and sometimes gold. In the Blue Bell mine a mixture of galena and sphalerite, rich in silver and gold, has been found in limited quantities, and small amounts of galena sometimes occur in the ore from the Gold King mine,[1] on Gold Hill, and the Dillon mine, on the Lawrence town-site, south of Victor, while 3 or 4 per cent of lead is said to have been detected by assay in some of the ore from the Deerhorn and other mines. Limited quantities of galena and other lead minerals carrying silver and gold occur in a number of places on Spring Creek, in the northern part of the Cripple Creek district. In the fall of 1894 some excitement was caused by the reported discovery of lead carbonate in this locality. A number of loose fragments of carbonate of lead and of galena, probably with some sulphate of lead partly converted to carbonate, all rich in gold and silver, were found on the Maggie Trimble claim, and a shaft was sunk in search of the ore in place, but so far without success.

ZINC MINERALS.

Zinc in important quantities is rare in the ores of the district, but occasionally small crystals of sphalerite occur in some places. These have been seen in the Little May mine, on Beacon Hill, and in the ore from a dike in a cut on the Florence and Cripple Creek Railroad, about half a mile south of Cripple Creek, while they are also said to have been occasionally seen in the ore of the Tidal Wave mine on Battle Mountain. The sphalerite from the Little May mine contains considerable quantities of iron and manganese. In some of the ore from the Blue Bell mine a very considerable quantity of zinc, in the form of sphalerite, has been found, as shown by the following analysis, kindly furnished by the manager, Mr. J. S. Lentz:

Analysis of ore from the Blue Bell mine.

	Ounces per ton.	Per cent.
Gold	0.60	
Silver	62.50	
Lead		8.50
Zinc		18.30
Iron		2.80
Silica		45.00
Water		1.50

COPPER MINERALS.

Copper in any form is extremely rare in the district, occasional specks of malachite or acanthite or other oxidized forms of copper being all that is seen, and even these occur in only very few places. An examination of a specimen of a copper-stained ore from the Gold King mine, in Poverty Gulch, made by Dr. Hillebrand, showed the presence of

[1] There are two Gold King mines in the Cripple Creek district, the one which is best known being in Poverty Gulch.

acanthite, a hydrous sulphate of copper. These oxidized copper minerals will probably pass into chalcopyrite at a depth.

At a pit on the Wilson claim on Bull Hill an antimonial tetrahedrite occurs, which, according to the results of Dr. Hillebrand, contains approximately 11.19 per cent of silver, 18.70 per cent of antimony, and 28 per cent of copper, with about one-half per cent of gold, which, however, is probably a mechanical admixture. This mineral, so far as known, is rare in the district.

ANTIMONY MINERALS.

Antimony has been identified in but few localities in the district. At the Blue Bird mine, on Bull Hill, a well crystallized form of stibnite occurs with quartz and fluorite. It is not found generally distributed in the vein, but occurs, so far as yet discovered, in only a few places. At the Wilson mine, on Bull Hill, an antimonial tetrahedrite occurs, as already mentioned under copper minerals.

FLUORITE.

Fluorite is a common mineral in many of the ores of the district and is usually prominent by reason of its brilliant purple color, though more rarely it is white or transparent. It generally occurs in a finely disseminated crystalline condition, or as isolated aggregations, or as thin parallel bands in the ore. Less commonly it is more coarsely crystallized in isometric cubes, with octahedral cleavage. Its most characteristic form is in intimate association with quartz, forming the brilliantly purple ore characteristic of many of the prominent mines of the dis trict, and known among the miners as "purple quartz." When this mixture of fluorite and quartz is exposed to the action of surface influences, the fluorite is gradually leached out, leaving a granular, friable, vesicular mass of quartz, more or less incoherent and commonly called "sand quartz" by the miners. A similar mass of granular quartz is often formed by the oxidation and leaching of innumerable small crystals of iron pyrites disseminated through a quartz matrix. The possible origin of the fluorite in this district and its relation to the gold is more fully discussed under the heading "Source and mode of deposition of the ores."

QUARTZ.

Quartz is the commonest of the secondary minerals found in the ores of the Cripple Creek district. It occurs in a number of different forms. Sometimes it is homogeneously disseminated throughout the ore, simply making it harder than it was originally; sometimes it appears in numerous thin parallel bands, or in interlacing films honeycombing the mass of the rock; while frequently it occurs in irregular bodies, and occasionally it increases in quantity sufficiently to form well-developed quartz veins, or to compose the cement of the fragments of country rock which

sometimes partly fill the fissures. The quartz occurs in various conditions, sometimes crystalline, sometimes massive, occasionally in mammillary forms, and more rarely in clusters of crystals radiating from a common center. Frequently it is found in intimate association with fluorite, forming a purple-colored mixture known by the miners as "purple quartz," which is more fully discussed on page 158. Occasionally an open, porous, more or less incoherent form of quartz, known in the district as "sand quartz," occurs, which represents simply a quartz matrix from which fluorite or iron pyrites has been removed by leaching, thus giving the mineral its open structure.

HYDROUS FORMS OF SILICA.

Numerous forms of opaline silica, in various degrees of hydration, are found in the district. Hyalite sometimes occurs in cracks in the dike of the Anaconda mine, while at the Victor mine a hydrous form of silica of a white, buff, brown, or brilliant-red color, called by the miners "jasper," is seen. This is one of the normal vein materials and sometimes composes a large part of the ore at this mine, while it occurs in smaller quantities in the Buena Vista and some of the other mines of the district.[1] It is massive and has a brilliant, glossy, conchoidal fracture. An analysis of the red variety of this material by Dr. Hillebrand gave the following results:

Analysis of "jasper" from the Victor mine.

	Per cent.
Silica (SiO_2)	72.46
Titanic oxide (TiO_2)	2.52
Alumina (Al_2O_3)	
Phosphoric acid (P_2O_5)	
Ferric oxide (Fe_2O_3)	17.88
Lime (CaO)	.14
Baryta (BaO)	Trace.
Magnesia (MgO)	Trace.
Potash (K_2O)	1.08
Soda (Na_2O)	.06
Lithia (Li_2O)	Trace.
Water (H_2O) below 110°	2.66
Water (H_2O) above 110°	3.04
	99.84

KAOLIN.

A large quantity of soft, argillaceous material is found in the ore bodies in both the granite and the eruptive rocks throughout the district, and has evidently been derived largely from the decay of feldspar and other aluminum compounds. Sometimes it is stained brown by iron or black by manganese, but very often it is pure white. It occurs throughout the mass of many of the rocks, but is most abundant along lines of fissuring, sometimes simply filling cracks, at other times in

[1] Occasionally the term "jasper" is applied by the miners to an ore composed of the homogeneous gray phonolite of the district, hardened by the infiltration of silica.

irregular masses, often a foot or several feet in diameter and intermixed with the quartz and other vein minerals. Analyses of this material show it to have a very similar composition whether derived from the granite or the eruptive rocks, and in all cases it is essentially a kaolin. The following analyses by Dr. Hillebrand show the composition of specimens from three different places. The specimen from the Albany tunnel is from the granite on the west side of Bull Hill; that from the Ida Bell mine is from the massive trachytic phonolite of Bull Hill, and that from the Summit mine is from the andesitic breccia of Globe Hill.

Analyses of kaolin from the Cripple Creek district.

	Albany tunnel (in granite).	Ida Bell mine (in massive trachytic phonolite).	Summit mine (in andesitic breccia).
Silica (SiO_2)	44.49	44.90	45.08
Alumina (Al_2O_3)	34.19	37.37	31.83
Ferric oxide (Fe_2O_3)	.53	.98	.95
Manganous oxide (MnO)	Trace.	Trace.	.....
Lime (CaO)	.26	.08	1.76
Magnesia (MgO)	.18	Trace.	.59
Baryta (BaO)	2.79	None.	Trace.
Potash (K_2O)	.30	Trace.	.14
Soda (Na_2O)	.07	Trace.	*a* .18
Lithia (Li_2O)	Trace.	.....	
Water (H_2O) below 110° C	3.42	2.14	6.64
Water (H_2O) above 110° C	12.91	14.59	13.32
Sulphuric acid (SO_3)	1.49	.08	Trace.
Phosphoric acid (P_2O_5)	.....	.....	.....
	100.63	100.14	100.49

a Strong trace of lithium.

An analysis of a similar material from the Gold King mine, in the eruptive rocks on the northwest side of Poverty Gulch, showed it to be essentially an impure kaolin, containing approximately 43.80 per cent of silica, 38.80 per cent of alumina, and 0.25 per cent of sulphuric acid, with 16.50 per cent loss on ignition.

CALCITE.

Calcite is one of the products of alteration of some of the eruptive rocks of the district, and it frequently occurs lining fissures or cracks or filling small cavities in dikes. It is possible that some of the calcite found may also be derived from the alteration of fluorite by alkaline carbonates or in other ways. Calcite, however, is not very abundant in any one place and is not a prominent feature of the ores of the district. Most of the "lime" indicated in the analyses of Cripple Creek ores is in the form of fluorite.

GYPSUM.

A white, compact, crystalline gypsum forms part of a vein in the bottom level of the Deerhorn mine (280 feet). In some places it is in bodies 10 feet or more in diameter and is associated with fluorite and

other vein minerals. Elsewhere in this mine thin films or crystals of gypsum often occur in the joints and other cracks in the country rock. No considerable bodies of gypsum have yet been noted in the other mines of the district.

OTHER MINERALS.

Besides the minerals already described others occur in small quantities in many of the mines of the district. A white mineral in spherical masses of radiating crystals and probably representing the mineral wavellite is found in small quantities in the Raven and Bertha B. mines. In concentrating certain ores of the district a very heavy, white material is often found, which is probably barite, though in some cases it may be carbonate or sulphate of lead. Barite is said to form as much as 46 per cent of the concentrates from certain ores at the Summit mine. A brown mica, partly, at least, biotite, occurs in the cracks and seams of a shattered eruptive rock on the Ocean Wave claim and is evidently a product of alteration. Mr. Cross describes mica as an alteration product elsewhere, but it is rarely in the large quantities found at the claim mentioned. In addition to these minerals numerous titanium, tungsten, and other rare minerals often occur in the ores, but these are more often the original constituents of the rocks in which the veins occur than secondary vein minerals, and they have already been described by Mr. Cross.

THE SUPERFICIAL ALTERATION OF THE ORES.

General features.—The action of air and surface waters on the superficial parts of the ore deposits of the district since their formation has caused, as in all mining districts, the oxidation and hydration of such of the minerals as could be thus affected, the formation of certain other new compounds by the action of materials held in solution in surface waters, and the leaching of certain minerals. Many of these effects have already been mentioned in discussing the various minerals which form the ores, but they will be here described together.

Depth of alteration.—The depth to which superficial alteration extends varies in different places, and is dependent on the topography of the country, the abundance and rapidity of downward movement of the waters by which the oxygen of the air and other materials in solution are carried into the veins, the chemical nature of the ore and of country rock, and their porosity and other physical and structural features.

At the time the district was examined for this report none of the mines had reached a depth greater than about 400 feet, and in very few of them had the downward limit of superficial oxidation been reached, so that a fair average of the depth of alteration in different places can not yet be given. In a few mines, however, the shafts had reached ores that were only slightly oxidized, and in these cases more or less oxidation had extended to depths ranging from 1 foot to over 200 feet, though some of the shafts which had reached almost 400 feet were

still in partly oxidized materials. In but few cases, however, is oxidation complete, even near the surface, and in most all the veins more or less unaltered materials occur with the oxidized parts; while, as has been stated, the gold, though generally converted to free gold near the surface, rapidly passes into the form of telluride and possibly auriferous iron pyrites at comparatively shallow depths.

Effect on iron, lead, zinc, copper, antimony, and manganese minerals.—By the action of this superficial alteration the iron pyrites is converted into limonite or other hydrous forms of the sesquioxide, while in some cases small quantities of hematite are found; and Pearce has shown the presence of a basic sulphate of iron, possibly the mineral glockerite.[1] Dr. Hillebrand has also shown that a phosphate of iron and possibly a variety of chloropal occur, and these are doubtless the products of the alteration of iron pyrites. (See p. 122.) Compounds of iron and tellurium which will be mentioned later are also found. The small quantities of galena, or lead sulphide, that occur are converted by superficial action into sulphate and carbonate, and the minute quantities of zinc, copper, antimony, and other sulphides are also converted into their respective oxidation products. The manganese has so far been found in no other form than that of oxide, though it is probable that with greater depth it may pass into the forms of carbonate or silicate, in which forms it is elsewhere often associated with sulphides of other metals; or possibly it may pass partly into a sulphide condition itself. (See p. 123.)

Effect on gold minerals.—It has already been shown that the original form of most, though not necessarily all, of the free gold was the telluride (p. 120) and to a small extent possibly auriferous iron pyrites. The effect of the oxidation of the telluride of gold has been not only to produce free gold, but to liberate the tellurium in an oxidized form, probably in combination with iron, though definite data concerning its condition after liberation are not yet available. In other districts besides Cripple Creek tellurium has been shown to be liberated from gold and other tellurides in an oxidized form, sometimes as tellurites, sometimes as tellurates, and often, if not generally, forming iron compounds. Emmonsite,[2] a ferric tellurite, was found in an oxidized ore from Tombstone, Ariz., while montanite and other related tellurium minerals probably also represent oxidation products. The tellurides of gold and silver are often intimately associated with sulphides, especially iron pyrites, and to a lesser extent sphalerite, galena, chalcopyrite, and other minerals, and it is probable that many oxidized tellurium and iron minerals are the products of the joint oxidation of the intimately admixed tellurides and iron pyrites.

Mr. Richard Pearce, who has done much to show the general distribution of tellurides in the sulphide ores of the Rocky Mountains,

[1] Proc. Colo. Sci. Soc., Apr. 5, 1894.

[2] W. F. Hillebrand, Proc. Colo. Sci. Soc., 1885, Vol. XI, pt. 1, pp. 20–23.

was the first to point out the occurrence of tellurium in an oxidized form in the altered parts of the Cripple Creek ores,[1] while somewhat later Mr. F. C. Knight[2] gave an analysis of a compound of tellurium and iron which he believes to be a tellurite of iron. Dr. Hillebrand has shown that oxidized tellurium and iron compounds occur in a specimen from the Prince Albert mine, and he has also proved the existence of oxidized tellurium compounds in specimens from the Raven mine, on Raven Hill, and the Wilson mine, on Bull Hill; but all these materials are too impure to determine whether the tellurium is in the form of tellurite or tellurate. Sufficient data have been collected, however, to prove clearly that oxidized tellurium minerals exist in the upper parts of the Cripple Creek ore bodies, just as in other regions where tellurides occur, but these oxidized minerals are usually disseminated in small quantities through the ore and are so intimately associated with iron compounds that they are with difficulty isolated. This is especially true of the iron and tellurium minerals not only at Cripple Creek, but in Boulder County, Tombstone, and elsewhere, so that the exact composition is in most cases somewhat doubtful, and all that can be definitely stated at the present time is that tellurites or tellurates, or both, doubtless occur and that there are possibly several different forms of them.

Effect on feldspar and other minerals.—Kaolin is a common product of the superficial alteration of feldspathic rocks in all regions, and it is not impossible that some of it in the Cripple Creek district has been formed in this manner; but that the vast bulk of it was formed previous to the action of surface alteration is proved by the fact that it shows no signs of decreasing in quantity with depth, occurring just as abundantly in the bottoms of the deepest mines as on the surface, while the frequent association of unaltered sulphides with large quantities of kaolin, as is often the case at Cripple Creek, is suggestive of the fact that the latter was not formed by superficial alteration, for if it had been thus formed the sulphides would have been oxidized. It is evident, therefore, that the kaolin is mostly a product of other causes, which, as shown on page 160, were waters rising from greater or less depths.

The gypsum found in some of the mines is possibly, though not necessarily, the product of the action of sulphuric acid or sulphates derived from the oxidation of sulphides on carbonate of lime or other calcium compounds derived from the alteration of certain eruptive rocks. In a similar manner various other less important compounds have resulted from superficial alteration.

Effect by leaching.—The effect of superficial alteration has been one not only of oxidation and hydration, but also of leaching, and many of both the original and the oxidized materials have been partly dissolved from the upper parts of the ore bodies. Part of the iron has

[1] Proc. Colo. Sci. Soc., Jan. 8 and Apr. 5, 1894.
[2] Ibid., Oct. 1, 1894.

doubtless been carried off in solution, while some, and possibly sometimes even a greater quantity, may have been brought in by surface waters containing iron derived from the oxidation of the iron pyrites common throughout the country rock. Other constituents soluble in the reagents contained in surface waters have also been more or less removed, though probably in some cases they were reprecipitated in other parts of the fissures. The fact that much of the free gold contains little or no silver, while the telluride from which it has been mostly derived contains a certain amount of silver, strongly suggests that the silver has been removed by leaching after or during the oxidation of the tellurides. Pearce[1] supposes that the silver has been removed by the solvent action of sesquisulphate of iron, and also suggests that the same solvent may have dissolved a part of the free gold, both of which processes may very possibly have occurred. It may be mentioned, however, that other chemical reactions possible in ore bodies of this kind may also have operated in the same direction.

One of the most marked effects of the leaching action of surface waters on the ore is the removal of fluorite from the intimately admixed fluorite and quartz characteristic of the district and commonly known as "purple quartz." In the upper parts of the ore bodies containing this material a friable, vesicular mass of quartz, often stained brown by the oxidation of disseminated iron pyrites and known by the miners as "sand quartz," frequently occurs and blends into the mixed quartz and fluorite below, thus showing that the removal of the fluorite is purely superficial. This leaching has probably been accomplished by surface waters containing solvents derived from the alteration of various materials. A similar form of quartz is also produced in some places by the oxidation and leaching of innumerable small crystals of iron pyrites disseminated through a quartz matrix.

VALUE OF THE ORES.

The value of the ores of the district varies very considerably, from a few dollars to several thousand dollars per ton. Most of the ore at present shipped from the mines, however, varies from $20 or $30 to $300 or $400 per ton, while the average of all the ore produced would probably be between $50 and $85 per ton. Some of the mines ship no ore averaging less than $100 per ton; a few have a production averaging over $200 per ton; and many have a production ranging from $25 upward per ton. The district is essentially a producer of high-grade ores, though in mining such ores considerable quantities of low-grade ores are produced, and with the constantly improving means of gold extraction lower and lower grades can gradually be used, so that the production of the district will be correspondingly increased.

[1] Proc. Colo. Sci. Soc., Apr. 5, 1894.

CHEMICAL COMPOSITION OF CALAVERITE FROM CRIPPLE CREEK, COLORADO.

By W. F. Hillebrand.

The occurrence of tellurium in the ores of the mining district of Cripple Creek, Colorado, has been known from an early day in the brief industrial history of that region. That it was, in part at least, associated with gold was likewise known from the observance of a crystallized gold-tellurium mineral. Although the ores of the district are chiefly gold carriers, they contain also a little silver, and since recognized silver minerals had not been observed, or at most only in minute amount, it seemed probable that the silver was associated with the gold in the tellurium compound. Indeed, Mr. R. Pearce,[1] of Denver, came to the conclusion, from analyses of oxidized and unoxidized ores, that this mineral was sylvanite, and he says, "Sylvanite itself appeared in little silver-white specks disseminated through a mass of greenish rhyolite, accompanied by amethystine fluorite." Notwithstanding that F. C. Knight[2] has identified calaverite by analysis and that sylvanite has not been identified by positive chemical or crystallographical tests, the evidence of Mr. Pearce as to its presence, in some portions of the district at least, is entitled to consideration. The telluride or tellurides are, however, of very sparing occurrence, so that it was only by dint of much effort that material in sufficient purity for decisive tests was obtained by Prof. R. A. F. Penrose, jr., who transferred it to me for chemical examination. The material was procured from three different mines in order to ascertain whether it was of constant or varying composition, or, in fact, whether there might not be more than one specific telluride. That the composition does vary within narrow limits the analyses show, but there is no reason apparent for assuming more than one existing species in the ores of these particular mines.

The material from the Prince Albert mine, the first received, was with little trouble brought into an almost ideal condition of purity. It was in part fairly well crystallized, and the most perfect crystals have been examined by Prof. S. L. Penfield, of New Haven. The specific gravity of this material was 8.91 at 24° C., which becomes 9 when corrected for a small admixture of silico-ferruginous gangue of assumed specific gravity 2.70 (probably low). The other samples were imperfectly crystallized and held too much foreign matter of uncertain composition to make specific gravity determinations of any value.

[1] Proc. Colo. Sci. Soc., Jan. 8 and Apr. 5, 1894.
[2] Ibid., Oct. 1, 1894.

Analyses of calaverite from the Cripple Creek district.

	I. Prince Albert mine.	II. Raven mine.	III. C. O. D. mine.
Tellurium (Te)	57.27	47.69	53.89
Gold (Au)	38.95	33.93	39.31
Silver (Ag)	3.21	1.47	.85
Insoluble matter	.33	5.80	.91
Ferric oxide (Fe_2O_3)	*a* .12	.....	.....
Iron (Fe)	.....	5.41	1.67
Sulphur (S)	.....	*b* 6.17	1.58 (2.96 Fe S_2)
Manganese (Mn)	.....	.....	*c* .23
Calcium (Ca)	.....	.....	.51
Magnesium (Mg)	.....	.....	.10
Oxygen, fluorine, and soluble silica by difference	.....	.....	*d* .95
Total	99.88	100.47	100.00

a This was included with the insoluble matter in arriving at the corrected density.
b Calculated from the Fe to make FeS_2.
c As MnO_2 ?
d A part of the calcium found in solution was derived from fluorite, which likewise constituted some of the insoluble matter in this instance.

Selenium has been reported by Mr. Knight (loc. cit.) to occur in oxidized ores of the district, but it could not be detected in the amount of mineral taken for the above analyses.

Excluding everything but gold, silver, and tellurium, and recalculating to 100, the following comparison is obtained:

	I.		II.		III.	
	Per cent.	Ratio.	Per cent.	Ratio.	Per cent.	Ratio.
Te	57.60	2.01	57.40	2.05	57.30	2.09
Au	39.17	1.00	40.83	1.00	41.80	1.00
Ag	3.23		1.77		.90	
	100		100		100	

The ratio here obtaining is that for sylvanite and calaverite, but the very low percentage of silver shows that the mineral is calaverite. Indeed the first analysis agrees almost exactly with Genth's analyses of the species. Interesting is the slight variation in the ratio between gold and silver and the very low percentage of silver in the mineral from the C. O. D. and Raven mines. Calaverite, the lowest silver carrier of the gold-silver tellurides, has not heretofore been known to carry less than 3 per cent of silver.

The pyrognostic characteristics of the mineral from the Prince Albert mine were essentially those ascribed to calaverite. In the closed tube it fuses, giving a white coating near the assay and a globular gray coating just above, which latter by strong heat can be in part driven higher up, leaving the glass covered with the same white fused coating as lower down. This latter is yellow while hot. On charcoal the mineral fuses with a green flame, giving a white coating and similar fumes and leaving a yellow bead. The color is pale bronze-yellow, in powder greenish-gray. The hardness is not less than and perhaps a little over 3. Specific gravity, as given above, 9.

The identity of the telluride occurring at Cripple Creek, which in oxidizing gives free gold and oxidized tellurium compounds,[1] seems thus satisfactorily established, but unless there is another richer in silver, as believed by Pearce, the mode of occurrence of the silver in some of the ores is still in large part unaccounted for. It may be derived from a very rich argentiferous tetrahedrite, a small specimen of which Professor Penrose submitted for identification. This carries over 11 per cent of silver, but is said to be excessively scarce, and, therefore, hardly to be considered in this connection, unless, indeed, this should have been the original source of most of the silver and later have suffered oxidation to a great extent, whereby the silver has become more evenly distributed throughout the ore.

W. F. H.

PARTIAL REPORT ON CALAVERITE CRYSTALS FROM CRIPPLE CREEK, COLORADO.

By S. L. Penfield.

The crystals of calaverite which were examined were developed with prismatic habit, but the prismatic zone was striated to such an extent that it was impossible to identify a single face in the zone, and on the reflecting goniometer almost an unbroken band of signals was obtained in a revolution of 360°. Owing to oscillatory combinations the crystals were also much distorted, so that they did not present regular cross-sections. The prisms were attached, so that doubly terminated ones were not observed, while the faces at the free end were small and developed with so little symmetry that after a study of a number of crystals it was found impossible to determine with certainty the system of crystallization.

The crystals do not exhibit the perfect cleavage ascribed to sylvanite and krennerite, but are similar to the former in some of their angles. When placed in position to show their relation to sylvanite they have their prismatic development parallel to the *b* axis. One crystal which, owing to its development, was more carefully measured than any of the others, was apparently a twin about 101, and showed at the end the forms 111 and 110. The measurements, compared with the corresponding ones of sylvanite, are as follows:

	Calaverite.		Sylvanite.	
	°	′	°	′
111 ∧ (111) over twinning plane	93	35	94	30
110 ∧ (110) over twinning plane	35	2	34	43
110 ∧ 111	36	35	37	3
110 ∧ 111 in the twin crystal	36	33	37	3

[1] From tests made by myself on a number of specimens collected by Professor Penrose the combination seems to be chiefly, if not altogether, with iron, but whether as tellurite or tellurate could not be ascertained. Knight (loc. cit.), however, has shown that the combination, in some cases at least, is a tellurite approximating to the formula $2\,(Fe_2O_3,\ 2\,TeO_2) + H_2O$.

Other forms which were measured could not be referred to the sylvanite axes, and it seems probable from their development and lack of symmetry that the crystals are triclinic, but no satisfaction was obtained after a long and careful study of the limited supply of material on hand. In conclusion, therefore, it may be stated that the crystals are probably triclinic, but near sylvanite in angles and axial ratio, and it is hoped that at a future time more material may be secured for a complete and satisfactory crystallographic study.

S. L. P.

SUMMARY.

The statements in this chapter may be summarized as follows:

The ores consist of the country rock more or less completely replaced by quartz with fluorite, opaline silica, and kaolin, and containing iron pyrites and other sulphides, as well as various other minerals, in limited quantities.

The gold occurs as free gold, as telluride of gold, and possibly as auriferous iron pyrites.

The free gold is derived largely from the oxidation of the telluride, and possibly to a limited extent from the oxidation of auriferous iron pyrites; while it is not impossible that some little of it may have been in the free state since it was deposited.

The telluride of gold is mostly in the form of calaverite, while sylvanite and other tellurides may possibly also occur.

Silver occurs in various forms in the ores, but with few exceptions it is in only very small quantities.

Quartz is plentiful, but not so common as in some gold districts.

The kaolin derived from the early alteration of the country rock is a common constituent of the ore.

Fluorite is a common constituent of the ore, and numerous other minerals occur in varying quantities.

Superficial alteration has caused the oxidation, hydration, and leaching of certain minerals in the ore deposits, as well as the formation of sulphates, phosphates, hydrous silicates, tellurites or tellurates, and other oxidized compounds.

The value of the ores shipped from the mines varies from $20 to several thousand dollars per ton. The district is at present essentially a shipper of only high-grade ores, but with increased facilities for treatment the large quantities of lower grade ores that occur can be used, and the production will be correspondingly increased.

CHAPTER III.

MODE OF OCCURRENCE OF THE ORES.

GENERAL CHARACTER OF THE GOLD DEPOSITS.[1]

The gold of the Cripple Creek district is found both in vein deposits and in placer deposits derived from the decay and erosion of the veins and country rock. Though the placers have produced considerable quantities of gold, the veins are far more important and supply most of the gold of the district. They generally occur in fissures in the country rock, which usually represent slight faulting, while more rarely they occur in other positions. The veins intersect all rocks in their course and have been formed mostly by a replacement along the fissures and not by the filling of open gaps.

GEOLOGICAL RELATIONS OF THE GOLD DEPOSITS.[2]

General features.—The district is essentially an elevated area of Tertiary volcanic breccia cut by numerous massive eruptive rocks in the form of irregular bodies and dikes, and surrounded on all sides by granite. Besides the intrusive bodies of eruptive rocks, the breccia area also contains massive eruptive rocks which were formed before the breccia area and which now represent included bodies. Bodies of granitic rocks are also included in a similar manner. The region of eruptive rocks is about 3 miles long in a north-and-south direction and about 2½ miles wide in an east-and-west direction, comprising an area of about 7 square miles.

Volcanic action.—From later Cretaceous well down into Tertiary times eruptive outbreaks were active throughout the country now occupied by the Rocky Mountains, and the vast quantities of lavas, breccias, tuffs, and eruptive materials of other kinds found in this region from Canada to Mexico were poured out largely during this period. The area now occupied by the mining district of Cripple Creek is in part on the site of a volcanic vent, or possibly of more than one vent, formed in Tertiary times. The region originally consisted entirely of granitic rocks,

[1] There is a very general idea among miners that the term "ore deposit," or simply "deposit," indicates a less valuable form of ore body than "vein," but there is no basis whatever for this idea, and the term as used here is simply a general expression to include the occurrence of a metal under any conditions, while the term "vein" is a specific expression indicating an occurrence under certain definite conditions, just as the term "placer deposit" indicates a certain definite mode of occurrence. The term "ore deposit" as used here includes both "veins" and "placer deposits."

[2] The general geology of the district has already been fully described by Mr. Cross, so that only a brief summary, necessary for the understanding of the nature and origin of the ore deposits, will be given here.

such as now compose most of the Pikes Peak range, but during the period of volcanic activity a vent or series of vents was formed, and was the scene of a series of explosive eruptions which ejected large quantities of eruptive rocks in a fragmental condition, thus forming the volcanic breccia which now comprises the larger part of the district and which includes bodies of the original eruptive rocks from which it was derived. Much of this breccia was thrown over the immediately surrounding granite, and at the end of the time of eruption the vent or neck itself was filled, choked up as it were, with the same breccia, so that the present area of volcanic materials is underlain partly by granite and partly by the filled-up vent.

After and probably during the outbreak of breccia eruptive masses of andesite, phonolite, and other rocks were intruded into the breccia area in the form of large bodies and of dikes. Some of these rocks overflowed a little on the surface, covering limited areas; but some of them, as seen now, show no overflow, though such may have existed once and may since have been eroded. The bodies of massive eruptive rocks are not confined to the breccia area alone, but also occur in the surrounding granite area, as seen on Mount Pisgah, Beacon Hill, Grouse Mountain, Little Pisgah Mountain, and elsewhere, while the whole of the immediately surrounding granite area is much cut up by dikes in the same manner as the breccia.

The dikes.—The dikes intersect all other rocks in the district, and pass indiscriminately from granite to breccia and from breccia to granite. They were the last signs of eruptive activity, and their appearance is evidence of the epoch of fissuring which lasted long after the dike action had ceased. They are of various compositions and from a few inches to many feet in width, generally, however, averaging from 1 to 10 feet. The fact that they intersect each other is evidence that they were formed at intervals during a certain period in the geological history of the district.

The degree of continuity of the dikes is difficult to determine on the surface, as there is generally a heavy covering of soil; but by some of the mining operations it has been shown that they often become thin and sometimes terminate abruptly, leaving a fissure or crack in the rock as the extension of their course. Sometimes fissures of this kind were formed along the course of the dikes after their intrusion, but at other times they were clearly formed before the dikes. (See p. 196.) Sometimes, also, the dikes fork and follow diverging fissures, though one arm usually thins out rapidly. The dikes run in a direction generally varying from northeast to northwest, though sometimes at considerable variance to these directions; but a general trend of this kind is distinctly more prominent than a more easterly and westerly trend.

THE FISSURES.

General features.—The nature and mode of occurrence of the ore in veins depend largely on the character of the fissures containing them, so that the latter will be discussed first.

The existence of the dikes already described necessarily implies the presence of preexisting fissures, so that a fissuring action undoubtedly began sometime before the formation of dikes. In fact, it is natural to suppose that such action was taking place during the whole of the eruptive epoch of the district. In some places the veins may occupy these early fissures, but in a general way the vein fissures do not seem to have been the earliest ones, though some of them were formed before the dike action ceased, and subsequently filled with ore (see description of the Pikes Peak mine). Evidence of the comparatively late date of the vein fissures, at least in the breccia area, is had in the fact that they are sharp, well-defined breaks with minute parallel sheeting, such as are formed only in comparatively compact rocks. Originally the breccia was in a soft and more or less tufaceous condition, but it has been since altered and converted to a comparatively hard rock. It is not likely that the sharp fissures and the minute sheeting and banding now seen in this rock could have been formed while it was in its unaltered condition, and therefore it is probable that they were formed after the rock was at least partly altered.

Alteration probably began soon after the formation of the breccia area, and some of the dikes were probably intruded in fissures formed after the rock had been more or less hardened. Evidence of this is seen in the fact that some of the later dikes occupy well-defined fissures with much parallel sheeting; and also in the fact that some of the prominent vein fissures are often intersected by dikes which were intruded before the deposition of ore. (See description of Pikes Peak and Buena Vista mines.) In the majority of cases which have been examined, however, the fissures occupied by veins were formed after the intrusion of the dikes, as is shown by the fact that they intersect the latter. This later fissuring action may have been intensified by the intrusion of the dikes, and was very prevalent all over the district, extending also far into the granite regions surrounding it. The later fissures sometimes follow the course of preexisting fissures, as is shown by the fact that they often intersect the dikes longitudinally; elsewhere they cross the previous fissures at various angles, as is shown by the fact that they intersect the dikes at such angles. In some cases, where a later fissure intersects a rude general fissuring in a transverse direction, it alternately follows and crosses the older fissuring, as shown in fig. 8, page 148. The whole region is much broken by numerous fissures intersecting one another at various angles. In any one locality one general course is usually more prominent than the other courses, though intersecting fissures of less prominence are always

present, and in some places there are two or more systems of parallel fissuring. The fissures are extremely numerous, and in many of the underground workings they are intersected every few feet.

Course of the fissures.—The general course of the fissures carrying the veins of the district, like that of the dikes, varies from northeast to northwest, and in many cases it is only very little removed from due north and south. Some of them occasionally strike nearer east and west, but in most of the important veins, with a few prominent exceptions, the more northerly trend is distinctly characteristic. More or less divergence in the fissures, however, is what would be expected in a region which has been previously subjected to such disturbances as have been described. Plates III and IV illustrate the parallel fissuring in the granite south of Victor.

Physical character of the fissures.—The fissures, as will be shown later, were not open gaps, but were almost closed lines of fracture, and the veins in them owe their presence largely to a replacement of the country rocks along their courses. Sometimes, however, the fissures were probably locally held open by the loose fragments of rock broken from the walls, or by protruding parts of the walls being brought opposite each other by movement along the fissure. The course of a fissure is sometimes marked by one clean-cut break, but usually parallel cracks of less prominence occur on either side. These subordinate cracks are sometimes so numerous as to give the rock in which they occur a banded, sheeted, or almost slaty structure for a width of from several inches to a foot or more on each side of the fissure, though usually they are somewhat too far apart to represent a slaty structure. Occasionally the cracks are not perfectly parallel, but two or more join each other along their strike, or one may fork and give rise to two separate cracks, which often combine again beyond. In California occurrences somewhat similar to these have been aptly called "linked fissures" by Mr. G. F. Becker,[1] in distinction from parallel fissures. Sometimes there are two or more main parallel cracks or fissures and numerous minor ones, while very commonly the zone of fracturing seems to be represented by no especially well-defined break, but by numerous parallel or approximately parallel cracks, each of about the same magnitude and from a fraction of an inch to several feet apart. These different phases of the fissures are represented in the figures on page 145.

Other similar breaks or cracks occur outside of these groups of fissures or fissured zones, but with increased distance they become farther and farther apart and less well defined until another zone of prominent fissuring is met. In fact, the district may be regarded as an area intersected by numerous zones of fissuring which are separated by areas of less marked but very noticeable fissuring, as represented in fig. 5, page 145.

[1] Geology of the Quicksilver Deposits of the Pacific Coast, Mon. U. S. Geological Survey, Vol. XIII, p. 410.

SHEETED ZONE IN GRANITE, EIGHT-MILE CANYON.

These groups of closely parallel fissures are probably due to a strong compressive stress in which the dislocation is spread over a series of parallel surfaces instead of being confined to one fissure. Mr. G. F. Becker[1] describes similar groups of fissures in the Washoe district of Nevada, and shows that the distribution of these lines of dislocation, when in a theoretically homogeneous mass, follows certain definite mathematical laws.

The fissures as fault planes.—The fissures occupied by veins are the result of movement which was probably accompanied usually by a certain amount of faulting, as is proved by the occasional occurrence of breccia in the better-defined fissures and the abundance of grooves or slickensides on the faces of the fissures. The amount of faulting is difficult to determine, as the country rock rarely offers any points by which the amount of throw can be estimated; and the slickensides, though they prove that movement has occurred, afford no indication of the amount of displacement, for they may be as prominent in faults of slight throw as of great throw. The clay selvage or gouge, which is believed by the miner to have been always formed by the rubbing of the wall rocks during movement, and is regarded as an infallible sign of faulting, is also found here in abundance; but very similar clays are formed by the decay in situ of the wall rocks, so that the presence of selvage or gouge is very uncertain evidence of faulting of any kind, and it is especially unreliable as an indication of the amount of faulting. Moreover, the surface is usually heavily covered with soil, so that observations on faults can, with few exceptions, rarely be carried on except underground, where, on account of the newness of the district, the development is necessarily limited.

Where dikes or fissures have been faulted, however, more definite data as to the amount of movement are often available, and the evidence so far obtained from this source indicates that the faults have throws varying from a fraction of an inch to several feet, and possibly sometimes much more. The greatest faults yet noted have throws not exceeding from 20 to 25 feet, as seen in faulted fissures in the Zenobia and other mines and in a faulted dike on the Ida May claim. These throws, however, are horizontal and may simply represent the horizontal displacement of faults which have a much greater displacement in another direction. It is not impossible, therefore, that somewhat greater faults than are at first apparent may have occurred along some of the fissures; but if the throws had been very great, even though the country rock offers few points by which the amount of throw may be determined, a difference in the structure or some other features would probably, in some cases at least, be observable in the rocks brought into juxtaposition. In a few cases such a difference may possibly occur, but in most cases the rocks on both sides of the veins,

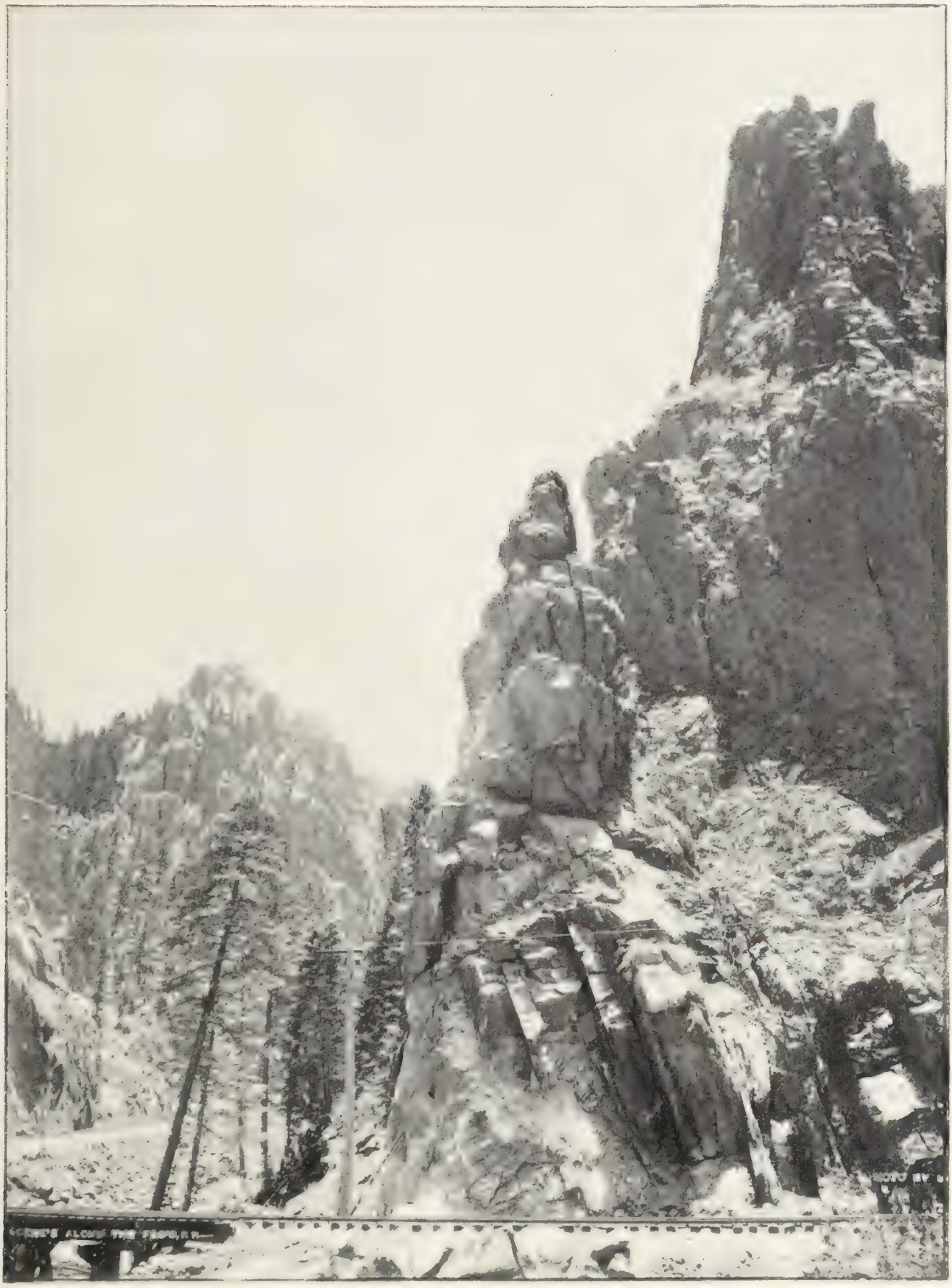
[1] Geology of the Comstock Lode, Mon. U. S. Geological Survey, Vol III, Chap IV

except, of course, where they happen to be at the contact of a dike with the country rock, are much the same.

One of the strongest arguments in support of the supposition that the faults represent small displacements is the physical condition of the fissures. In the cases where the fissures occur in closely parallel groups (fissured zones), any considerable movement would have destroyed this structure, for, no matter how plastic, any rock in such a minutely banded condition as is seen in many of the mines could not have been subjected to very much movement without being shattered or brecciated. The brecciated fissures which occur may denote more movement, other things being equal, than the fissured zones, but they are not continuous for any very great distances and rapidly pass into the latter, a feature which would not occur if they had been caused by any very considerable movement. In fact, the amount of brecciation in a fissure is not necessarily an indication of the amount of movement, for brecciation depends more on the character of the rock and the nature of the force producing fracturing than on the amount of displacement. In a general way, however, the brecciated fissures represent more disturbance than the fissured zones, for in most brecciated fissures masses of rock can be found showing the parallel fissure structure possessed by the fissured zones before brecciation occurred.

The evidence, therefore, all seems to point to the fact that the veins occupy lines of movement, that this movement was accompanied by more or less faulting, and that the faulting, though greater in some places than others, was rarely very extensive. At the time of the formation of the breccia, during the active volcanic manifestations, profound faulting may of course have occurred; but since the time the vent was filled with breccia the district in general seems to have been subjected only to a series of more or less violent shocks, possibly often in the nature of earthquakes, and the result of these disturbances has been that the district has been slightly faulted in every conceivable direction, and that the fissures extend beyond the eruptive area into the surrounding granite. Outside of the immediate Cripple Creek district, however, faults of much greater magnitude, sometimes with a displacement of over 1,000 feet, are described by Mr. Cross.

It has been suggested by some that faulting was the cause of the granitic breccia occurring between the granite rim and the central area of volcanic breccia in the district. This material forms a belt from a few feet to several hundred feet in width, and is seen at many places where the contact of the granite and the volcanic breccia is visible. Granite fragments are common throughout all the breccia and in some of the dikes, having been derived originally from the granite walls of the vent, but such fragments are most prominent near the granite rim of the eruptive materials. In fact, in passing from the granite to the volcanic area there is a gradation from massive solid granite to granite very much shattered and broken; then to where this shattered



SHEETED ZONE IN GRANITE, EIGHT-MILE CANYON.

rock is thrown out of place and brecciated; then to a mixture of fragments of volcanic material with fragments of granite, and then a gradual decrease of the granite fragments and a corresponding increase in the volcanic fragments. These transitions sometimes cover a width of several hundred feet, at other times much less, and sometimes, though rarely, the massive granite comes sharply up against the volcanic breccia.

There are several strong arguments to show that this granitic breccia was formed during volcanic activity from the rim rock, in the same way as the breccia of eruptive materials was formed from eruptive rocks in the interior of the vent:

(1) The gradual transition from purely granitic to purely volcanic breccia would not occur in a fault breccia, where there might be fragments of both, but where the transition would be sharp, or at least confined to a comparatively narrow zone.

(2) There is no structural or topographical evidence to indicate dynamic movement sufficiently great to cause such an immense amount of brecciation as is seen. The granitic breccia, like the whole region, is much broken by slight faults, but the faults usually represent throws of only small extent.

(3) The zone of the granitic breccia can be seen, with but few exceptions, wherever the contact of the granite area and main area of volcanic breccia is visible. It can be traced almost continuously from a short distance south of the town of Cripple Creek to the south end of Battle Mountain. Elsewhere on the border of the old vent there is either an overflow of breccia or a heavy covering of soil, so that it is impossible to see whether or not the granite-breccia completely surrounds the district. In the central part of the main breccia area, however, there is a large mass of included granite, several hundred yards in diameter. This is almost encircled by a breccia showing the same gradation from granitic to volcanic materials as is seen around the granite rim. Here there can be no doubt as to the origin of the granitic breccia, as it could have been formed by no other cause than volcanic action; and as this breccia is exactly similar in both character and behavior to that around the old rim, it is natural to suppose that the latter also had a similar origin.

Effect of the country rock on the character of the fissures.—The character of the fissures of the district is much affected by the nature of the rocks they intersect, and in following a fissure from one kind of rock to another marked changes are often noticeable. In the massive, hard, or brittle rocks, like the granite and some of the massive eruptives, or like some of the hard breccia, the fissures are much sharper and better defined than in the softer and more plastic rocks, like the soft breccia, especially that which has not been much altered and is tufaceous. Even among the massive rocks the distinctness of the fissures varies considerably. A given force, therefore, may cause a

well-defined break in some rocks, while in others it may be manifested by a much fainter break or by only a group of parallel cracks.

The principal fissures in the great bodies of massive eruptive rocks on Bull Hill are sharp, clean-cut breaks, often filled with fragments of country rock broken from the walls during the movement that produced them, and it is to the easy fracturing of this rock that the well-defined fissures of this part of the district are due. The vein on which the Buena Vista, Lee, Smuggler, and Victor mines are located occupies a sharp, clean-cut fissure, partly in the massive rock and partly in the hard breccia; but when it passes into the soft tufaceous breccia on the east slope of Bull Hill the fissure is represented only by faint cracks occupied by no vein of importance. In this case the force which caused the fissure overcame the cohesion of the harder rock sufficiently to make a clean break, but in the more plastic rock it overcame cohesion only to the extent of causing a series of faint fractures without any one well-defined break. In the Independence mine the ore in the granite has been formed by impregnation and replacement of the country rock along a well-defined fissure, while where the fracture passes through the phonolite dike, it breaks up into a series of thin parallel cracks spread over a width of 3 or 4 feet. (See Pl. XIV). In the C. O. D. mine the vein occurs in a fissure in a hard breccia, and the force which formed the fracture was sufficient not only to produce groups of parallel and often peculiarly diverging cracks, but also to make a sharp, well-defined fissure.

THE VEINS.

General features.—What has been said of the general mode of occurrence of the fissures holds true for the veins, which are simply bodies of secondary minerals filling the fissures. Sometimes the veins represent single well-defined bodies of ore filling one fissure, and sometimes they occur in a number of thin parallel seams, filling the fissured zones already described. Frequently two or more parallel zones of fissuring containing ore occur close together and are separated by isolated breaks or fissures either carrying ore or barren. The accompanying figures (2, 3, 4, and 5) illustrate these various modes of occurrence. The veins are found in all the rocks of the district—breccia, massive eruptive rocks, and granite. They have in many places been followed down in mining for depths of several hundred feet without showing signs of exhaustion.

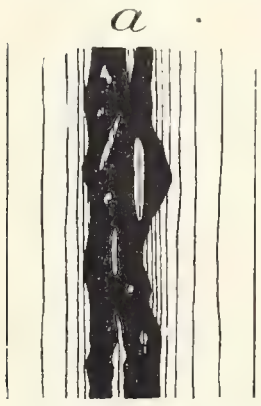


FIG. 2.—Ideal section showing the mode of occurrence of ore in the Cripple Creek district. a = vein.

Arrangement of vein materials in the fissures.—The ore lines both sides of the fissures or, more commonly, both sides of each of the series of parallel fissures characteristic of the district, and gradually blends

into the country rock beyond. The different vein minerals are usually promiscuously mixed, and are rarely arranged in bands parallel to the walls, as might be the case in ore deposited in an open fissure. The ore generally appears to be simply the country rock containing greater or less quantities of secondary minerals, which decrease in amount with distance from the fissure along which they were deposited; and in different places every gradation can be seen from fissures along which the rock has been only slightly impregnated to fissures where most of the ore is composed of secondary minerals blending into inclosed masses or sheets of rock, and finally to the rarer cases where the ore is wholly composed of secondary minerals. In cases where this impregnation goes on along a series of close parallel cracks, it extends out from each crack, and as it grows more and more extensive the deposits in different cracks combine into one or more larger deposits.

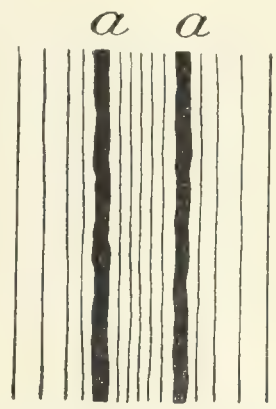


FIG. 3.—Ideal section showing the mode of occurrence of ore in the Cripple Creek district. *a*, *a*, veins.

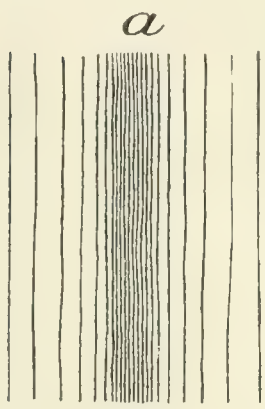


FIG. 4.—Ideal section showing the mode of occurrence of ore in the Cripple Creek district. *a*, vein.

Ore deposition often takes place only along certain of the parallel cracks of a fissured zone, and leaves others comparatively unaffected. When the impregnation in the cracks which are affected extends laterally to the barren cracks it often ceases there, leaving a sharp line separating the ore from the rock. Such planes as these are regarded by the miners as walls, and as many miners have a superstition that a "good wall" is the making of their mine, irrespective of anything else,

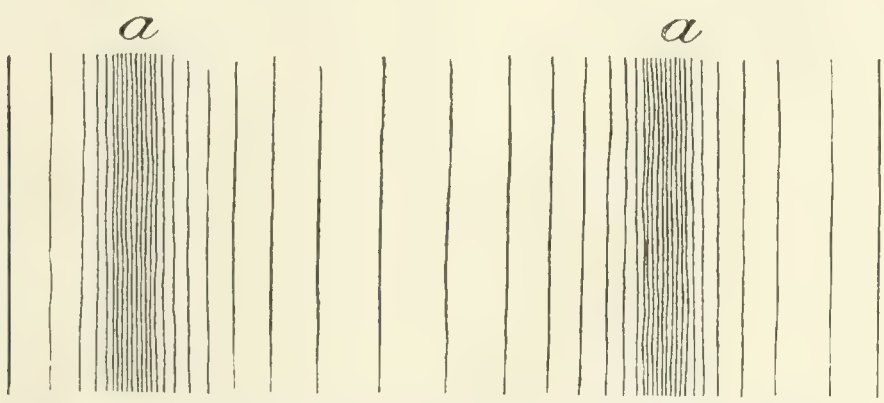


FIG. 5.—Ideal section showing the occurrence of parallel zones of fissuring containing ore and separated by isolated fissures either carrying ore or barren. *a*, *a*, veins.

they stop right there and follow it as the side limit of their ore. In all districts, and especially at Cripple Creek, this is the wrong thing to do, for ore deposits often occupy a series of parallel positions, and these

treacherous "walls" should be constantly crosscut to search for parallel veins. Though such so-called "walls" as those described are found in many or most of the mines of the district and give the impression that the ore is sharply divided from the country rock, yet wherever the impregnation is not checked by a barren parallel crack the ore is seen to blend into the country rock without any sharp dividing line, becoming scarcer and scarcer until it entirely disappears in the barren rock.

Such occurrences as those described leave no doubt that the ore of the district is largely, at least, a replacement of the country rock along very narrow fissures which were hardly more than cracks, though occasionally it appears to have locally filled open places along them, produced either by the sides being held open by fragments broken from the wall rocks, or by two convex places in opposite walls being brought together by movement along a fault fissure. Occurrences of this kind are seen in a few cases, as in certain parts of the Pharmacist vein in the Zenobia mine, where the vein minerals form the cement of fragments of country rock collected in the fissure, while in places in the Little Mary, Granite, Blue Bell, and other mines a tendency to a banded structure is sometimes seen, which may be due to ore deposition in local open places, though occasionally an apparent banding is caused by the original sheeted structure of the replaced rock.

Ore-bearing and barren fissures.—Though the fissures of the district are very numerous, they have not in all cases become the repositories of bodies of ore. As a rule, the stronger and more profound fissures, other things being equal, are more likely to carry ore than those not so well defined, and it is not unusual for several parallel fissures carrying ore to be separated by other parallel but poorly defined and barren fissures; but in some cases fissures of small extent carry ore while more profound ones are barren, and such occurrences are probably due to a difference in the conditions at the time of ore deposition. All the fissures, however, whether they carry ore or not, contain thin films or disseminated crystals of iron pyrites, which were probably deposited by solutions acting on the district before the ore-bearing solutions, as shown on page 161.

Relation of veins to dikes.—It is a noticeable feature of the whole district that veins often follow dikes, either throughout their course or, more commonly, for short distances, and that when a vein meets a dike, though it may sometimes cross it directly, it is very likely to be deflected and to follow the dike for greater or less distances. This association of veins and dikes is particularly prominent in certain parts of the district, especially in places on Raven Hill, Battle Mountain, and elsewhere, and it has led many to believe that the dikes always indicate the courses of the veins and that the veins are true contact deposits between the dikes and the country rock. Such, however, is rarely the case except in isolated instances. Ore deposition was a sequel of the dike action, and as it depended on heated rocks for much

of its effect it would be more likely to occur in the region of the latest eruptive rocks, which were the dikes, than elsewhere. The dikes may also have cut water channels existing in the country rock before their intrusion, and the water from such channels, thus forced up the sides of the dikes, might have caused ore deposition. Moreover, the shrinkage cracks formed in the dikes at their contacts with the country rock may sometimes have offered favorable places for ore deposition. In some cases these causes have doubtless had more or less effect in producing a connection between dikes and veins, but in the vast majority of cases where the veins follow dikes the association is clearly due to the effect of the dikes in directing the courses of the later fissures in which many of the veins were deposited.

The dikes represent lines of weakness, not only because they occur in the course of older fissures, but because of the shrinkage cracks formed along their sides in cooling, and also because of the state of tension produced by their intrusion. Moreover, the contact of two different rocks may often be a line of weakness because of the unequal physical properties on either side. All these causes make the courses of the dikes easy lines of fissuring. As the disturbances which produced the later fissures occupied by veins acted in the same general direction as those which produced the fissures occupied by the dikes, and as the courses of the dikes were lines of weakness, it was natural

FIG. 6.—Ideal section showing the relation of veins to dikes. *a*, veins; *b*, dike.

that the later fissures should often follow them, and this is found to have occurred in many cases. As the general direction, however, of both the dike fissures and the later fissures is somewhat variable, the latter often cross the dikes. Sometimes the later fissures cross the dikes directly, but usually, especially when they meet them obliquely, the later fissures are deflected along the dikes for a greater or less distance, and then finally leave them and follow on their normal courses. When the fissures follow the dikes they generally adhere to one side of them or the other, as the shrinkage cracks make these positions lines of easy fracture; but frequently they cross and recross the dikes at short intervals, and where they leave or meet either side a branch from the vein occupying them usually runs a few feet from the main ore body out along the part of the shrinkage zone not followed by the fissure. The accompanying figures (6, 7, and 8) show the relation of veins to dikes in different places.

What is true of the relation of the fissures and the veins in them to the dikes along their strike is also true of them along their dip; sometimes they follow them, sometimes they cross them directly, and sometimes they are deflected along them for greater or less distances.

It may be added here that the ore seems as apt to occur with one kind of dike as another, and, though the nature of some of the vein minerals may vary with the nature of the dikes, the gold, so far as yet known, does not seem to be affected.

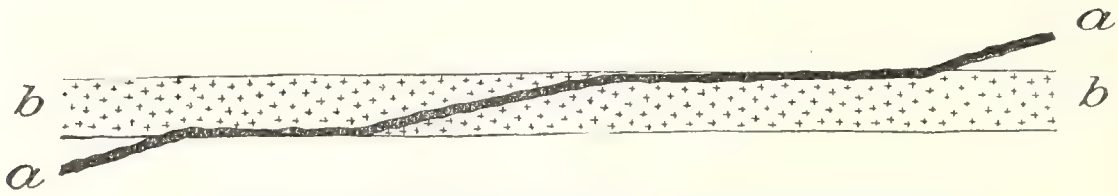


FIG. 7.—Ideal section showing the relation of veins to dikes. *a*, vein; *b*, dike.

A deflecting influence similar to that already described in the effect of dikes on veins is often seen where vein fissures cross diagonally another series of preexisting fissures, as shown in fig. 9.

Changes in veins and dikes at a depth.—Geologically the Cripple Creek district is comparatively young, and though erosion has caused many changes in the topography, yet it has not so completely obliterated the

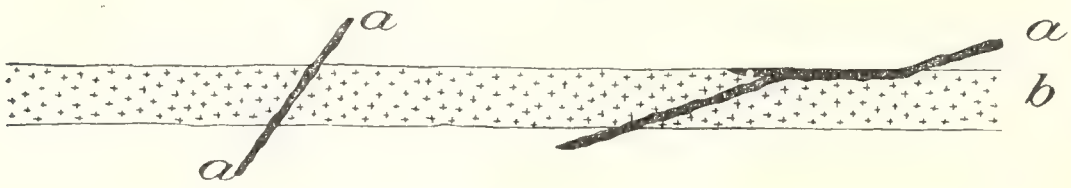


FIG. 8.—Ideal section showing the relation of veins to dikes. *a*, veins; *b*, dike.

character of the upper parts of the formations as in some older districts. The dikes and veins especially, which mark the latest formations in the district, seem to show evidence of only limited erosion, for their

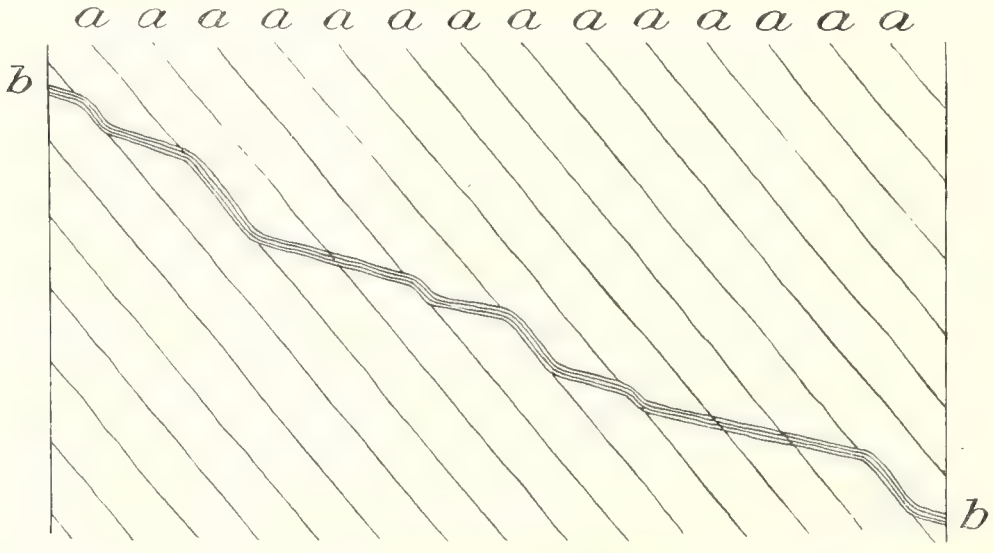


FIG. 9.—Ideal section showing the influence of previous fissures on the course of later fissures. *a*, earlier fissures; *b*, later fissures.

upper parts often, though not always, differ markedly from their deeper parts. The dip near the surface is frequently at a different angle from that at a depth, and veins which occur in one well-defined fissure at a depth sometimes fork near the surface and appear in separate outcrops.

Both these phenomena can be attributed to the fact that at a depth the fissures occupied by the dikes or veins were confined to the original line of breakage on account of the superincumbent pressure, while nearer the surface this pressure was relieved, numerous transverse breaks of more or less superficial character were encountered, and the fissures were more easily deflected and divided. Such effects are not seen in all parts of the district, or even in most parts, for erosion has usually removed all signs of them, but they are especially noticeable in some of the less eroded places. Even in such places much of the superficial part of the dikes and the veins has of course been removed, but these effects are often still observable to depths varying from 50 to 200 feet or more, when the dikes and veins assume more regular courses.

Doubtless similar phenomena once occurred in all mining regions, but in most of them erosion has been sufficient to remove all signs of the original surface of the fissures, so that now only the parts that were once at considerable depths are seen. Mr. G. F. Becker,[1] however, shows that in certain mercury deposits of the Coast Ranges of California the veins fork into numerous branches near the surface and become concentrated in single fissures at a depth, and he suggests that such occurrences are due to the fact that the upper parts of the veins as seen now represent what were the upper parts when the fissures were originally formed, and that, though some erosion has occurred, it has not been sufficiently great to remove entirely the old surface zone.

Later movements in the veins.—After, and possibly during, the filling of the fissures with ore, more or less movement sometimes occurred along them, for in some of the veins the mineral contents are cut by longitudinal breaks or are slightly shattered and distorted. More or less of a similar movement also seems to have taken place along minor fractures that cross many of the veins, for the latter are sometimes cut by indistinct cross-cracks. In some cases these cross-cracks follow older breaks of greater movement which carry seams of ore, in the same way as the longitudinal cracks just described in the main fissures; in other cases they represent fresh breaks of later date. In all these cases of later movement, however, the disturbance was very slight, and often scarcely noticeable. It seems to have been the conclusion of the series of dynamic disturbances which affected the region.

Ore deposition in shrinkage cracks.—Sometimes cracks or sheeted zones occur in dikes at their contacts with the country rock, and follow all the curves in the meanderings of the dikes in a manner that would not be likely to characterize independent and subsequent fissures. The banded structure here is probably caused by the shrinkage of the dikes along the contact with the country rock during cooling. Sometimes these cracks are not confined to the sides of the dikes, but occur,

[1] Geology of the Quicksilver Deposits of the Pacific Coast, Mon. U. S. Geological Survey, Vol. XIII, pp. 412–413.

though less distinctly, all through them, in a manner that makes it difficult to distinguish them from the cracks produced by subsequent dynamic disturbances; but by following the dikes for considerable distances it is usually possible to determine this point, for when the dike curves sharply the fissure produced by a later disturbance cuts directly across the curve, while the shrinkage cracks follow it. In many cases, however, the lines of the shrinkage cracks, being lines of easy fracturing, were followed by subsequent fissures which happened to have the same course as the dikes; so that the shrinkage cracks and the later fissures are often both found along the same line. The fissures and the veins filling them pass alternately from one side of the dike to the other, and where they leave or meet either side a branch from the vein usually runs a few feet from the main ore body out along the part of the shrinkage zone not followed by the fissures, as shown on page 147.

The shrinkage cracks are probably not so deep-seated nor so far-reaching as the fissures, and therefore, when unaffected by fissures, they probably have rarely become the repository of important ore bodies. In mines where only a limited amount of work has been done, however, it is often difficult to say whether the ore occurs in shrinkage cracks or in fissures caused by later movement, so that it is impossible as yet to determine exactly how important shrinkage cracks alone, when otherwise unaffected, may be as repositories of ore.

Region of the richest veins.—The most profitable mines yet discovered in the Cripple Creek district are in the eruptive rocks or in the granite immediately adjacent to the main volcanic vent or vents, as is more fully discussed on page 155. Outside of the immediate Cripple Creek district gold occurs in a number of places; in fact, a certain amount of gold is characteristic of almost all the Pikes Peak region. The peculiar type of deposit at Cripple Creek, however, already described, is not known in this region outside of certain definite limits, though it is possible that somewhat similar deposits, in association with other volcanic vents like those at Cripple Creek, may yet be found in the less-known part of the Pikes Peak region or in the great volcanic area to the west. Gold has been worked at a number of places in the past thirty years in the granite area far outside of the Cripple Creek district, but in few of them has it yet proved a profitable industry. Active prospecting, however, is still going on, and it is possible that valuable deposits may yet be found.

THE PLACER DEPOSITS.

General features.—Though, as has been shown, erosion in the Cripple Creek district has not been very great since the intrusion of the later eruptive rocks, yet it has been sufficient to alter considerably the general surface features, and the region is now characterized by a series of smooth, rolling, grass-covered hills, occupying an elevated position among the granite foothills of the west slope of Pikes Peak. The veins

THE EMMA PALMER PLACER, CRIPPLE CREEK.

were eroded in the same manner as the country rock, and the gold in the eroded parts, when freed from the inclosing rock, was concentrated, by virtue of its greater specific gravity, in the gravels in the gulches and low places, thus forming the placer deposits of the Cripple Creek district. The country rock itself, especially where much altered, probably contains some gold outside of the veins, and this source also may have supplied a part of the gold in the placer deposits.

The placers that have been worked lie chiefly immediately north and west of the town of Cripple Creek, and occupy the hollows in the amphitheater of hills surrounding the headwaters of the stream of Cripple Creek. In many other places, however, smaller placers occur, and have been worked to a limited extent. On Cripple Creek, below the town, small placers are found, and have been worked; on Globe Hill some of the surface soil was rich enough to mill; on the south slope of Bull Hill placer ground has been found near Hull's camp, while in several places on Beaver Creek and in Squaw Gulch, Arequa Gulch, and on Wilson Creek limited areas of placer ground occur; but all of these, on account either of their small extent, low grade, or lack of water, have been but little operated.

Principal placers.—The main placer fields back of Cripple Creek are sufficiently extensive and of sufficiently good quality to be of importance. They have been worked in various ways—by the pan, rocker, sluice, and by various forms of dry washers—but have been opened up only superficially. The water used in the wet processes has all to be obtained from pumps or other limited sources, so that the production is constantly curtailed, and is much less than it would be with abundant water. This scarcity of water has prevented any attempt at hydraulic mining. In spite of the various difficulties, however, these placer grounds have produced considerable quantities of gold, and will doubtless produce much more. Those best known are the Hayden, Pikes Peak, Freeman, and Cripple Creek placers. The ground is worked on the lease system, and small areas are let to individuals. A man with a rocker can obtain from $3 to $10 per day from good ground, while, if especially fortunate, he may occasionally get from $20 to $30 per day. Plates V and VI show the Pikes Peak and Emma Palmer placers, while Plate II, page 111, shows the general area of placer ground above the town of Cripple Creek.

USEFUL GUIDES FOR MINERS AND PROSPECTORS.

From the above discussions several facts which will prove useful to the miner and prospector become evident:

(1) The veins occur in great numbers, and very often a series of parallel veins extends over a width of many feet of country rock. In mining on any one of these veins frequent crosscuts should be made in search of parallel veins, for it is always possible that equally good and often better ore occurs in a vein parallel to and only a few feet

away from a vein in which much time and capital have been expended in exploration. Of course, crosscuts may also disclose parallel veins of no value, or barren fissures containing no ore, or even no veins or fissures of any kind, but the possibility of finding parallel veins of value warrants frequent cross-cutting in every mine in the district. This method of operation has been carried on in only very few of the mines, and probably a number of good properties have been abandoned as worthless on account of neglect of it.

(2) It has been shown (p. 145) that frequently certain planes of movement in the country rock are looked on by the miner as the "walls" of his vein and are supposed to be the side limits beyond which no ore occurs. These supposed walls frequently do not mark the limits of the ore, but are only divisional planes in a zone of ore deposition, and therefore they should be constantly blasted into in order to be sure that no ore is left on either side of what has been considered and worked as the vein. There are a number of mines in the district which have suffered on account of the delusion caused by these so-called walls.

(3) It has been shown (p. 162) that the pay ore in this district, as in most gold districts, does not occur continuously throughout the course of the veins or fissures, but in more or less isolated bodies or shoots. If, therefore, a well-developed vein is found which does not contain good ore in the place being worked, search should be made for a shoot in other parts of the vein. Most of the shoots that have been found in the district, though not all, reach the surface and usually dip downward at steep angles, so that if a shaft is not on pay ore it is best to prospect for a shoot by cross-cutting the vein on the surface or by drifting on it underground. The shoot when found may extend downward for a very great depth, but not only are the chances of finding it by cross-cutting on the surface or drifting much greater than by sinking, but these operations are also much cheaper than sinking. A shaft might be sunk on poor ore between two shoots which would be found by a little drifting or surface cross-cutting. In some of the mines of the district it has been shown that ore shoots do occur at a depth and do not come up to the surface. Such shoots might of course be found by sinking a shaft when they might be missed in a drift which passed over their apex; but as the shoots which come to the surface are the more common it is always best to prospect for them before going to the expense of sinking a shaft to any very great depth in barren ground. If it is considered well to sink a deep shaft after prospecting superficially, drifts should be run out from it along the vein at frequent intervals.

In some cases the gold may have been partly removed from the upper part of a vein by superficial leaching, so that better ore may be found at a greater depth; but this condition is of such uncertain occurrence that it can not be relied upon, and in a general way it is not safe to count on better ore at a depth than near the surface, though such may be the case in some places.

THE PIKES PEAK PLACER, CRIPPLE CREEK.

(4) It has been shown (p. 146) that the veins often follow dikes, and therefore it is always well to examine the dikes for ore. A great many veins have no connection with dikes and a great many dikes contain no veins, but in a general way the course of a dike is a likely position for a vein. If the dike itself contains no ore it is well to make cross-cuts on the surface in search of veins outside of the dike, as fissures containing veins often occur parallel to and a few feet away from dikes.

SUMMARY.

The statements in this chapter may be summarized as follows:

The gold of the district occurs in both vein deposits and placer deposits, though the veins are by far the more important.

The veins occur in and near an area of eruptive rocks which overlie and partly surround a volcanic vent and which are themselves surrounded by granite.

The veins occur in fissures which were formed at a comparatively late date in the history of the district.

The fissures are usually represented by one main fracture with numerous subordinate parallel fractures, though sometimes two or more main fractures occur close together, and frequently there is no one especially well-defined break, but there are a number of closely parallel fissures of about equal magnitude.

The fissures represent fault planes of slight displacement.

The fissures are markedly affected by the character of the country rock through which they pass.

The veins blend laterally into the country rock of which they are largely a replacement.

Veins do not occur in all the fissures.

The veins frequently have certain definite relations to the dikes, generally because the vein fissures often followed preexisting dikes, but sometimes for other reasons. A somewhat similar relation is seen between veins and preexisting fissures not occupied by dikes.

The parts of the dikes and veins which were near the surface at the time they were formed have in some cases not yet been entirely eroded, so that they are more irregular in dip and form near the surface than at a depth.

Later movements of small extent have in some cases occurred along the vein fissures and elsewhere after the veins were formed.

Ore has in some cases been deposited in shrinkage cracks in dikes along their contact with the country rock.

Placer deposits occur in a number of places in the district, but the most important ones are at the headwaters of Cripple Creek, just above the town of that name.

Various points of practical value to the miner and prospector can be derived from the features described in the present chapter.

CHAPTER IV.

SOURCE AND MODE OF DEPOSITION OF THE ORES.

GENERAL STATEMENT.

The nature and mode of occurrence of the ore in the Cripple Creek district have already been described, and it is the object of the present chapter to discuss briefly the possible source of the gold and the associated secondary minerals, and the processes which have brought them into their present position. The limited time available before the publication of this report has made it impossible to carry on all the chemical investigations necessary to discuss in detail the various processes of the formation of the veins, but such preliminary statements will be made as are warranted by present knowledge, and a further discussion will have to be reserved for a future time.

SOURCE OF THE GOLD AND ASSOCIATED METALLIFEROUS MATERIALS.

It has already been shown that the fissures occupied by veins in the Cripple Creek district represent fault planes. As all rocks, even the most brittle and rigid, must be regarded as more or less plastic bodies when considered in connection with dynamic movements in the earth's crust, it is necessary to believe that any fault, no matter how great a displacement it may have, must at certain depths become less and less prominent until it disappears. It should be said here, however, that though this depth is slight in comparison with the diameter of the earth, yet in many cases it is far greater than could be reached in mining, so that the above statement is in no way intended to refer to the downward limit of ore from a practical standpoint. In such fissures as those in question, therefore, the ore may have been derived from anywhere between the surface and greater or less but not extremely profound depths. Ore-bearing solutions may of course have risen through the interstices of the rock from a much greater depth than that reached by the fissures; but the circulation from depths very much greater than the fissures must necessarily have been slow, and it must have become of less and less importance as those depths increased.

It is probable that the ore has not been derived exclusively from deep-seated sources, nor exclusively from shallow sources, nor exclusively from the immediately adjacent parts of the rock, but from the whole area of the rock whose underground drainage during the time of ore deposition was tributary to the fissures. In the case of Cripple

Creek the ore occurs in some places in eruptive rocks and in some places in granite, and as it is probable that these two rocks extend downward as far as any possible depth from which the ore could be derived, it is to one or both of them that it is necessary to look for the source of the ore. These rocks have not as yet been examined carefully enough to prove their contents of gold when in an unaltered state, though they both have been shown to contain it when altered. In altered rocks, however, it is difficult to determine whether the gold is an original or a secondary constituent, and the source of the gold is ascribed to these materials more because similar rocks elsewhere carry it, and because, in the present case, there seems to be no other possible source, than because sufficient accurate data as to the presence of gold in the rocks when unaltered are as yet available.

As regards the relative importance of the later eruptive rocks and the granite as sources of gold, it is probable that the former were the more prominent, possibly not so much on account of their greater contents of gold as on account of their peculiar environment. It is a notable fact that throughout the district the richest veins occur in eruptive rocks or granite in the vicinity of the vent or vents from which the former were produced; and the history of the district so far shows that the veins, though they may carry throughout their courses an abundance of quartz, fluorite, and other secondary minerals, grow poorer and poorer in gold with distance from the vents. The concentration of gold in fissures requires not only a source of gold, but also the reagents—generally hot solvent solutions under pressure—necessary to dissolve the disseminated metal, carry it into the fissures in their course, and there, by one or more of many methods, deposit it. Such a combination of conditions is of comparatively rare occurrence. In many rocks gold is disseminated in small quantities, and such rocks, when subjected to the proper conditions, may be the source of gold for rich ore bodies, while the same rocks, or even rocks richer in gold, if not subjected to these conditions, may retain the gold in its finely disseminated and practically valueless condition. It is perfectly possible that a combination of the proper conditions might cause the concentration of gold from either the eruptive rocks or the granite in the Cripple Creek district, but in this region the conditions for the concentration of the gold seem to have been extensively realized, so far as yet shown, only in the neighborhood of volcanic vents where, as the result of subsiding eruptive activity, the rocks were subjected to the action of hot waters impregnated with various solutions, and these waters seem to have been the reagents which dissolved the gold and caused its concentration in fissures. Hence the veins are rich in and near the area of the vents, and become poorer as distance increases; and hence, also, the eruptive rocks, being more abundant than the granite in the vents, probably supplied most of the gold, though the immediately adjacent granite may have supplied a certain share.

The other rarer metalliferous constituents, like the small quantities of silver, lead, zinc, antimony, and copper which occur, were probably derived from the country rock in a manner similar to that in which the gold was derived, while the iron, manganese, barium, and other common constituents were also doubtless derived from various parts of the surrounding rocks. Iron and manganese are common in most eruptive rocks and granites, and barium is common in small quantities in many feldspars.

The causes which have resulted in the gold being in the telluride form require more experimental tests and research than it has been possible as yet to carry on, so that the full discussion of these questions will have to be left for the future. Gold and some other metals have been shown by Becker[1] to be soluble in certain solutions of alkaline sulphides, while silica also is soluble in certain sulphides, and it, as well as other earthy bases, is soluble in solutions of alkaline carbonates. Such agencies are usually suggested to explain the association of gold and other metallic sulphides in quartz veins, and they would not only account for the presence of many of the constituents of the ordinary auriferous deposits, but also for the sulphide form of many of the metallic constituents. The condition of gold in the form of telluride, however, requires a further explanation.

Tellurides of gold and silver occur in a number of places in the Rocky Mountains, but preeminently in Boulder County and Cripple Creek, though they also occur in smaller quantities in the San Juan region, La Plata County, the Rosita Hills, Lake City, and elsewhere in Colorado; at Bannack City and elsewhere in Montana, and in Calaveras and other counties in California, as well as in many other places in the West, while they have also been shown to occur in small quantities in close association with sulphides in most of the ores of Leadville and Gilpin County, Colo.[2] In fact, as suggested by Pearce, it is very probable that a more careful search will show the existence of certain quantities of tellurides of gold and silver in many ores which have been heretofore supposed to be purely sulphide ores. Therefore, before any conclusions are attempted on the subject, tellurides should be carefully sought in the various sulphide ores of the Western country, as well as in foreign countries, and their mineralogical associations and their geological occurrence should be noted, so that, if possible, certain general facts may be established. At the present time but little is known of them except that a number of different forms of tellurides of gold and silver exist; that they often are associated with bismuth; that tellurides of lead, mercury, nickel, bismuth, etc., also occur; that these various tellurides often contain selenium; that they are almost always associated with sulphides, especially iron pyrites, and to a lesser extent sphalerite, galena, copper pyrites, etc.; and that on exposure they

[1] G. F. Becker, Am. Jour. Sci. (3), Vol. XXXIII, 1887, p. 199.
[2] Richard Pearce, Proc. Colo. Sci. Soc., Vol. III, Pt. III, p. 257.

oxidize and form various tellurites and tellurates, especially in combination with iron.

The close association of tellurides with sulphides, especially iron pyrites, which themselves often carry gold, is also a point worthy of note. Not only are auriferous tellurium and sulphur compounds often thus mechanically associated in different minerals, but sometimes they replace each other in the same minerals, such as tetradymite, nagyagite, and tellur-sulphur. Such associations are what would be expected in view of the fact that tellurium and sulphur have many points in common in their chemical behavior, and this fact, as well as their intimate association in nature, makes it possible that somewhat similar agents, such as alkaline sulphides, alkaline tellurides, etc., may have affected the concentration of both sulphides and tellurides. In this connection it may be added that the presence of large quantities of alkaline minerals is especially characteristic of many of the crystalline and eruptive rocks of all ages in the region in question. Fluorine minerals are also equally characteristic of both the older and younger rocks, and a feature which may eventually be of some assistance in explaining the occurrence of tellurides of gold is their common association in Boulder County and Cripple Creek with fluorite, as more fully discussed on pages 158–159.

SOURCE OF THE FLUORITE.

The fluorite characteristic of the Cripple Creek ore bodies has a somewhat uncertain source. It is a well-known fact that fluorine compounds are common in the vapors from many modern volcanic vents, and flourine minerals are found in many of the districts of past eruptive activity in the Rocky Mountains, though as associates of gold they are rare. On the other hand, numerous fluorine minerals, such as fluorite, cryolite, tourmaline, and topaz, occur in the granite of this part of Colorado; so that there are two possible sources for the fluorine found in the Cripple Creek veins: First, the volcanic materials, and second, the granite. It is, of course, not impossible that the volcanic materials may have derived their fluorine from the surrounding granite, thus making the granite the ultimate source of this material. It has been shown by Mr. Cross that hydrofluoric, hydrochloric, and sulphuric acids might readily be evolved from the phonolitic magma during solidification, and he also suggests the granite and the vapors of indefinite source evolved from the fumaroles which were once probably abundant in the district, as other possible sources of the fluorine.

The fluorine which now occurs in the veins is, so far as known, all in the form of fluoride of calcium, fluorite. It is not at all improbable that the fluorine originally came into the fissures in a volatile or soluble form, such as hydrofluoric acid, or, more probably, as some of the hydrofluosilicates, or as soluble fluorides, and there encountered solutions which carried carbonate of lime derived from the decay of the eruptive

rocks or from other sources. The natural result would be the formation of fluoride of lime. If the fluorine had been previously in the form of hydrofluosilicic acid the precipitation of fluorite would have been accompanied by a deposition of silica, and as the two materials would thus be formed at approximately the same time the result would be the intimately associated mixture of quartz and fluorite known as "purple quartz," which is distinctly characteristic of the district.

A microscopic examination of thin sections of this mixture of fluorite and quartz ore from the Blue Bird and Summit mines shows it to be composed of a matrix of crystallized quartz, sometimes with a radiating structure, containing crystallized fluorite. In any one specimen the fluorite is distributed through the mass in a comparatively homogeneous manner, but in different specimens the relative proportions of quartz and fluorite vary greatly, from cases where most of the material is quartz to cases where over half is fluorite, though usually quartz predominates. Generally, but not invariably, the fluorite is in isolated crystals and in groups of crystals, with well-formed angles. The usual perfection of the fluorite crystals would suggest that this mineral was probably deposited before the quartz, but the uniform mixture of the two minerals makes it necessary to assume that both were deposited at very nearly the same time, and it seems possible that the perfection of the fluorite crystals may be due to the fact that the quartz which was deposited with them was in a gelatinous form and gave them ample opportunity to develop.

A noticeable feature of the fluorite is the variation in the density of the purple coloring matter. As seen in thin sections some of the crystals are a light purple, some a dark purple, and some are colorless; while in places dark spots occur from which the purple coloring matter seems to radiate and to grow fainter as it gets farther away. It is believed by many that the coloring matter of fluorite is due to the presence of organic matter, and it is not impossible that these minute spots may represent such material.

Besides the minerals mentioned as occurring in this fluorite and quartz ore, crystals of iron pyrites are also frequently seen, as well as, more rarely, telluride of gold, stibnite, and other minerals, but the mass of the ore is a homogeneous mixture of quartz and fluorite.

RELATION OF THE FLUORITE TO THE GOLD.

The presence of fluorite may possibly have some connection with the presence of gold, but the quantity of one is no definite indication of the quantity of the other. In certain rare cases the best ore is looked for where the fluorite becomes most abundant; but this relation is the exception, and in the same mine the fluorite ore sometimes contains large amounts of gold, sometimes but little, and sometimes none, while on the other hand the ore rich in gold contains equally variable quan-

tities of fluorite. Any possible connection that may exist between the presence of fluorite and the presence of gold probably depends on the existence of the gold in the form of telluride, for in the regions where gold occurs in its common form of auriferous iron pyrites, fluorine minerals rarely occur with the ore; but in certain regions where the gold occurs as tellurides, notably at Cripple Creek and in Boulder County, Colo., the two great telluride districts of the Rocky Mountains,[1] fluorite is common. In other words, the connection, if any, seems to be not between the fluorine or its compounds and gold per se, but between fluorine or its compounds and tellurium or telluride of gold. In support of this supposition it may be said that tellurous oxide (TeO_2) is well known to have a marked power of absorbing anhydrous hydrofluoric acid, and it is not impossible that a similar affinity may exist between other fluorine and tellurium compounds.

SOURCE OF THE KAOLIN.

Kaolin occurs in large quantities in and around many of the ore bodies. It generally blends gradually into the country rock, which shows every stage in the degree of kaolinization, the effect being most noticeable near the fissures and decreasing away from them. The mode of occurrence of this mineral leaves no doubt that it is derived from the feldspathic or other aluminum constituents of the country rock, and that its present position is not far removed from the part of the rock that produced it. The only other prominent aluminum mineral as yet observed in the Cripple Creek district is a mineral probably representing wavellite, which occurs in cracks in the rock in a few places, and has probably been derived, like the kaolin, from the alteration of the adjacent rocks. The various other alteration products of feldspathic rocks, such as alunite, diaspore, gibbsite, bauxite, and other minerals, have not yet been identified in the Cripple Creek district; but it is by no means improbable that they may yet be found, for alunite and diaspore are common results of the alteration of certain eruptive rocks in the Rosita Hills,[2] and alunite often forms a part of the "Chinese talc" of Leadville,[3] while allied compounds elsewhere are often supposed to be the result of alteration of eruptive rocks.

Sometimes calcite occurs lining narrow cracks or filling small vesicles in some of the eruptive rocks, especially in certain dikes, and it is doubtless often derived from the alteration of certain of these rocks. In some places its mode of occurrence seems to suggest a local derivation somewhat in the manner of kaolin, while in other places it may be

[1] Fluorite also occurs in some of the gold and silver ores of the Mogollon Mountains in New Mexico, while W. B. Devereaux (Engineering and Mining Journal, Vol. XXXI, 1881, p. 39) mentions the occurrence of fluorite in gold-bearing veins at Kings Mountain, North Carolina; but outside of these localities fluorite is rare in the United States as an accompaniment of gold.

[2] Whitman Cross, The Geology of the Rosita Hills, Proc. Colo. Sci. Soc., Vol. III, Pt. III, 1890, p. 277.

[3] S. F. Emmons, Geology and Mining Industry of Leadville, Mon. U. S. Geological Survey, Vol. XII, 1886, pp. 603–606.

derived from wider-spread sources.[1] It is also possible that some of the calcite found may have been formed by the action of alkaline carbonates on fluorite.

SOURCE OF THE QUARTZ AND OTHER FORMS OF SILICA.

Silica may be derived in part from the immediately adjacent rocks, as it is a product in the formation of kaolin from feldspar; but probably the mass of it has been derived from various outward sources, as all the rocks of the district are capable of supplying it.

ORE CONCENTRATION BY AQUEOUS ACTION.

Evidence of aqueous action.—In the preceding discussion it has been assumed that the constituents of the ore which were derived from outside rocks were brought into the fissures in solution in certain liquid solvents, except possibly in the case of certain fluorine compounds which may have been in a gaseous form. It may be added, however, that as these solutions were usually hot their action may often have been hastened by steam and other vapors.

Evidence of the action of liquid solutions is had in the manner of alteration of the rock, the removal of certain constituents which are not volatile alone or in combination with any gaseous solvents which might have been present, and the deposition of certain other nonvolatile materials, as well as in many other features of the veins. The ore-bearing solutions were probably hot, for they passed through eruptive rocks which had in all probability not entirely cooled off at the time ore deposition went on; and, moreover, by analogy with other regions where similar geological events have happened at more recent epochs, it is seen that hot-water action is a natural sequel of volcanic action. Additional evidence of hot-water action is had in the fact that cold waters could probably not have accomplished the extensive alteration and deposition seen in the district in such a limited time as has occurred since its action.

Effect of aqueous action.—The open, porous character of the breccia composing the mass of the district allowed the free percolation of these altering solutions, and even the massive eruptive rocks were more or less permeated throughout, for no rock is entirely impermeable. The result was that in some places the rock was extensively kaolinized and left in a soft state, in others extensively silicified and hardened, while in some places it seems to have been first kaolinized and then silicified. In all cases iron pyrites were deposited in disseminated crystals throughout the rocks of the region. In one place large quantities of brown mica crystals have resulted from this alteration, but the prominent product of alteration in this district is kaolin, though, as shown by Mr. Cross, mica in microscopic crystals is common. So extensive has

[1] Calcite occurs in comparatively small quantities and is not a prominent vein mineral. Most of the "lime" shown in the commercial analyses of the Cripple Creek ores is in the form of fluorite.

this altering action been that the fragmental character of the breccia is often completely obscured, except under microscopic examination.

Relation of alteration and ore deposition.—Though the altering solutions permeated throughout the mass of the rocks, they naturally tended to circulate most abundantly along the fissures and the innumerable lines of fracture by which the district is intersected, so that it was along such breaks that the most extensive alteration and deposition occurred, and for this reason the veins occupy the fissures. It has been shown, however (p. 139), that the veins occupy fissures that were formed after alteration had considerably affected the country rock, so that the ore could not have been deposited until after that time, and it is not impossible that these later solutions may have differed somewhat in their contents from the earlier ones. Further evidence of this action of different solutions is had in the fact that all the fissures, throughout their courses, contain thin films or disseminated crystals of iron pyrites evidently deposited during alteration and rarely containing much gold, while the true ore not only does not occur in all the fissures, but even in the same fissure occurs only in certain places. In other words, the early altering solutions seem to have acted everywhere throughout the district, while the later solutions acted only locally.

In some places, especially at the Independence and other mines in the granite, alteration has caused the removal of mica and quartz, and has left a porous vesicular skeleton of feldspar, often partly kaolinized. The removal or kaolinization of the feldspar is a process which might be produced by the simplest solutions, such as carbonic acid and water, but the removal of quartz and the leaving of the feldspar is a process which required more than ordinary reagents. This effect is most prominent in fissures in the vicinity of phonolite dikes or at the contacts of such dikes with the granite, and it has been suggested by Mr. Cross that it may be due to fluorine compounds evolved from the phonolitic magma. Certain fluorine compounds act on both quartz and various silicates, but the relative effects on different siliceous minerals, as shown by him, is not yet sufficiently well known to permit us to ascribe this action definitely to such a cause, so that this point will have to be left for future chemical investigation. It is not impossible that alkaline solutions may also have had some effect in this peculiar alteration of the granite.

Mode of ore deposition.—All the chemical changes which went on during ore deposition can not be fully determined for lack of sufficient evidence as to the chemical nature of the solutions which altered the rock and deposited the ore. It has been shown, however (p. 146), that the ore is largely a replacement of country rock and was rarely deposited in open fissures. The process of removing the rock and depositing the ore may have gone on by a chemical reaction between the rocks and the ore-bearing solutions, or the constituents of the rock may have been first gradually removed and then the ore almost simultaneously

deposited in their place without the intermediate formation of cavities of any size. Though the former process may have had its effect, the evidence at present available would suggest the primary removal of parts of the rock and the subsequent deposition of ore. The deposition of the ore in this case may have been caused by a reaction between the metalliferous solutions and other solutions met in the fissures, while a simple dilution of the metalliferous solutions by those of different character may have rendered them unable to retain their burden in solution, and may have in this way also produced precipitation. These effects may also have been assisted by the other changes in conditions experienced by the solutions as they approached the surface, such as relief of pressure, cooling, slackening in the rapidity of flow, and other conditions.

ORE SHOOTS.

General features.—In Cripple Creek, as in other gold districts, the gold is not uniformly distributed throughout the fissures in which the veins occur, but it is concentrated in certain parts of the fissures into bodies of ore of varying shape, size, and continuity, known as ore shoots or ore courses.[1] In its more restricted sense the term, when used in connection with fissure deposits, applies especially to a part of a vein richer in certain metalliferous constituents than the other parts, though the latter may contain certain amounts of these metalliferous constituents and just as much of the other secondary vein minerals as the shoot. The term, however, is also often applied to bodies of ore in fissures which, outside of the limits of these bodies, contain little or no vein matter of any kind. Such deposits are better known as ore chimneys, but in many cases they are looked on by the miner as shoots, and there is really no good reason why the term should not be expanded so as to include them. They differ from the more commonly recognized shoots in being isolated bodies of vein matter instead of simply rich spots in otherwise well-developed veins. The shoots in the Cripple Creek district represent both of these classes of deposits.

The Cripple Creek shoots are of varying shapes and richness, and they trend in various directions in the fissures, though possibly in many of them a general southern pitch down and along the fissure is more common than any other. This is most often noticeable where the course of the shoot is guided by certain transverse fissures, to be mentioned later. Elsewhere the shoots may dip vertically, and more rarely a little to the north. They vary from one to several hundred feet along the fissures and from a few inches to several feet in thickness. In some places they have a well-defined columnar shape, in others they have forms of no regularity whatever. In some places they outcrop at the surface, in others their apex is many feet below the surface; in some

[1] The following discussion relates only to ore shoots in fissures, as in the Cripple Creek district. The shoots occurring in other forms of deposit may be due to a variety of different causes irrelevant in the present connection.

places they are very continuous in depth and extend as deep as they have yet been followed, in others they come to an end at a comparatively shallow depth, though occasionally these shallow shoots are replaced by others at a greater depth.

Various causes of ore shoots in fissure deposits.—In many mining regions the position of rich ore bodies is determined by the rocks in which they occur, and in passing from one rock to another a fissure may be alternately rich and poor in ore, or it may carry an abundance of certain metals in one rock and an abundance of others in another, thus causing local accumulations or shoots of different materials. These occurrences are used by the strict lateral secretionists as arguments that the ore has been derived from the rocks immediately adjacent, and in some cases, such as the veins in the fahlbands of Norway, this argument may have some force; but in most cases it seems more probable that the change in ore in different rocks is due to the fact that one rock may cause the precipitation of certain materials from the circulating solutions and another rock may cause the precipitation of others, or else the waters draining from different rocks may likewise cause the precipitation of different materials from the same solution.

It is a well-known fact that in Cornwall, England, many of the veins are rich in copper where they intersect the slates and rich in tin where they intersect granite, while in Freiberg the character of the country rock has sometimes a very marked effect on the richness of the ore.[1] In many places it is noticeable that where a vein crosses a stratum highly impregnated with organic matter the deposition of ore is much larger than elsewhere, and Rickard shows that a certain stratum of this kind in Ballarat, Australia,[2] has such a marked effect in this way that it is used as a guide in searching for ore and is called the "indicator," while somewhat similar occurrences are described by C. B. P. Searer in the Gympie Reefing Fields of Queensland.[3] When a series of parallel veins cross a certain stratum of this kind which has a decided effect on the precipitation of ore, the rich places in each vein of course lie along a transverse line intersecting the various veins in the direction of the strike of the special stratum in question, thus giving rise to the miners' expression "ore against ore." In a similar manner, in a series of interbedded limestones and siliceous rocks, ore deposition is often more extensive in the limestone than elsewhere.

All such occurrences as these are easily explained by the different action of different rocks, or of the solutions draining from them, on ore-bearing solutions passing through the fissures. In the Cripple Creek district, however, the rocks are often quite uniform along fissures in which in different places the amount and richness of the ore varies greatly, and though possibly in a few places a change in rock may have

[1] B. von Cotta: A Treatise on Ore Deposits, translated by F. Prime, jr., 1870, p. 50.
[2] T. A. Rickard, Proc. Colo. Sci. Soc., Sept, 4, 1893.
[3] Jour. Roy. Soc., New South Wales, 1887.

had its influence, yet this has probably been more a mechanical effect on the fissure or an effect on the course of the ore-bearing solutions than a chemical effect on ore deposition.

In many districts it is observable that where veins intersect stratified rocks the course of the shoots in the veins is often influenced by the direction of lines of stratification, or where certain lines of fracture in any kind of rock cross the main fissures occupied by veins they also often have an influence in producing the distribution of shoots known as "ore against ore." In the Cripple Creek district cross fractures have undoubtedly had a marked effect in the course of some of the ore shoots in individual veins or fissures (see description of C. O. D. mine), but the system of "ore against ore" has not been observed, though it may yet be shown to exist.

Influence of the local occurrence of ore-bearing solutions.—In spite of the large number of veins in the Cripple Creek district there are many fissures in which little or no ore has been deposited, and there is in different places a gradual transition in the amount of ore from fissures which contain none to fissures which are highly impregnated. Moreover, individual fissures are sometimes impregnated with vein minerals for only certain distances along their courses, and sometimes this impregnation is confined to the chimney-shaped bodies of ore already mentioned.

The conditions in the barren fissures or in the barren parts of individual fissures often seem to have been quite as favorable for the deposition of at least the more common vein minerals as in the places where ore has been formed, except possibly that in the latter the fissures are more shattered and offer an easier passage for waters, so that it seems probable that the unequal content of ore is due to the fact that the solutions from which it was deposited passed along only local channels and did not impregnate either all of the fissures or even every part of individual fissures. Such local occurrence of hot waters is a natural sequence of the volcanic action which was formerly prevalent in the district, and is in complete accord with what is going on now in many regions of more recent igneous activity, such as at Steamboat Springs, in Nevada, the Yellowstone Park, in Wyoming, and elsewhere. The action was probably of a fumarole nature and had its effect along numerous more or less separate channels, sometimes spreading along a fissure and depositing ore for considerable distances, sometimes localizing its action along chimney-shaped channels. The upward course of the ore-bearing solutions was guided by the more open places, which offered easy channels, such as shattered or brecciated areas along the fissures or places where the occurrence of intersecting fissures made the main fissure more permeable than elsewhere.

Influence of cross fissures.—In the best-defined ore shoots there is often an intimate connection between the course of the shoots and certain cross fissures often representing lines of slight dislocation. These

cross fissures have either deflected the ore-bearing solutions from the main fissure and guided them along certain lines or else they have acted as channels for other solutions, either descending or ascending, which have caused precipitation from the solutions in the main fissure. There is no reason, however, why these cross fissures should have carried ascending or descending solutions different from those in the main fissures; and as they are usually very much smaller than the main fissures, the amount of solutions they would afford, if of the same nature as in the main fissures, would not have the marked effect observable in determining the course of the shoots. It seems more probable, therefore, that the effect of the cross fissures in localizing ore shoots has been largely a mechanical one in deflecting the course of ore-bearing solutions, and in support of this it may be said that the ore frequently runs out laterally along these transverse fissures for several feet from the main vein, as notably seen in the new Washington shaft.

Illustrations.—The explanations already given fully account for the local presence of ore along fissures in chimney-shaped bodies; and to this class some, if not most, of the best-known ore shoots in the district belong, such as those at the C. O. D., Anna Lee, Orpha May, Washington, and possibly the Morning Glory and other mines. The ore shoot in the C. O. D. is especially suggestive of the influence of cross fissures in guiding the ore-bearing solutions. It will be seen in fig. 15, page 170, that the under side of the shoot follows in different parts of its course two different sets of cross fissures, and that it is bounded sharply by these breaks. The ore shoot at the Anna Lee mine is a chimney-shaped body of ore formed along a zone of fissuring in a position which probably offered an especially easy channel for the movement of waters, as explained on page 205. The ore shoots in the Orpha May mine consist of a series of almost vertical narrow chimneys, as shown on page 198.

Other influences.—Besides the shoots or isolated chimneys of ore previously described there are, as already stated, other shoots representing rich places in veins which, outside of the shoots, are just as well developed as in the shoot and carry the same quartz, fluorite, iron, and other secondary materials, except that they contain less gold, and sometimes, though rarely, none. For such occurrences a further explanation than that already given is required. It is possible that in the solutions rising along a fissure the common vein materials were uniformly present throughout, but that the gold existed in quantities in certain parts and not in others. The extreme narrowness of the fissures might by capillary action prevent the solutions from becoming thoroughly mixed in their ascent, and therefore the deposits formed in one part of a fissure might readily contain more gold than those formed in another. Ore shoots of this kind might also be formed by the occurrence of the conditions necessary to precipitate gold in certain places along a fissure and their absence elsewhere; while the conditions necessary to precipitate the commoner vein minerals existed not only where

the gold was deposited but also in other parts of the fissure, so that the result would be a well-defined vein with important quantities of gold in certain parts only.

It is a noticeable fact that where a fissure crosses a dike the latter often seems to influence the amount or, more rarely, the grade of the ore. The influence is usually on the amount, for in some of the softer dikes of the district the fissures are often narrower and not so well defined as in some of the other rocks, and hence here the effect is purely mechanical. Sometimes, however, the grade of the ore seems also to be affected, as is shown in the Eclipse mine, in which the best ore occurs near where the fissure intersects a dike. The influence of the dike in such a case as this may be because it is a manifestation of later eruptive action than the inclosing rock, and therefore waters rising along the part of the fissure cutting it may have been hotter and may have possessed greater chemical activity there than elsewhere along the fissure; or it may possibly be due to the fact that in such cases the rocks from which the waters rose contained more gold than occurred elsewhere; or that the dike contained better precipitants for gold than the surrounding rocks. Where a fissure follows a dike instead of crossing it, any influence that the latter may have is of course felt along the fissure throughout its course, as is seen at the Elkton and other mines.

In conclusion, it may be said that, except in a few cases, sufficient development work has not yet been done in the Cripple Creek district to clearly define the ore shoots; and, moreover, there is a reluctance on the part of many mine owners to give or to allow to be gotten sufficient data to determine the nature of the shoots in their mines.

SUMMARY.

The statements in this chapter may be summarized as follows:

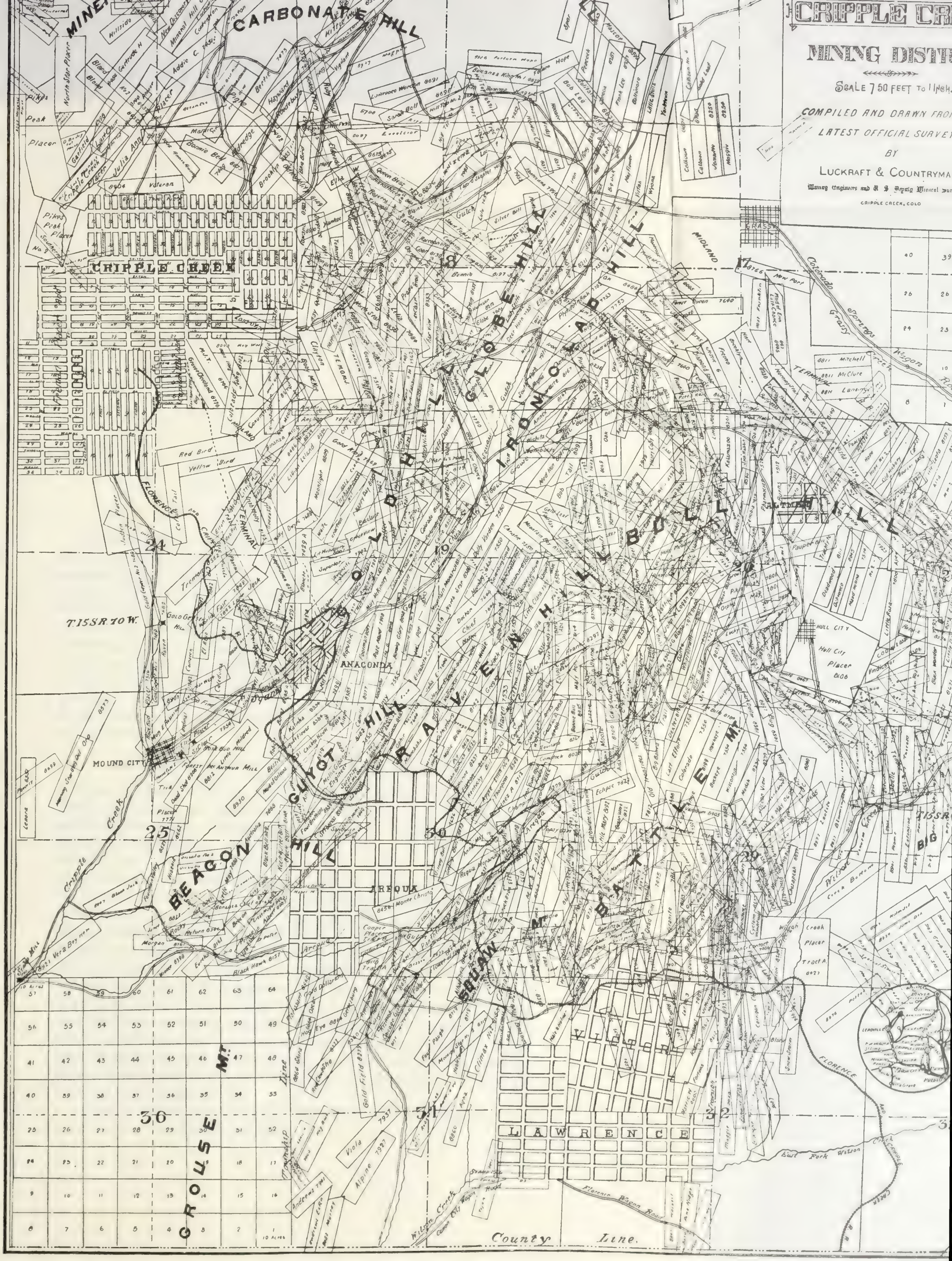
The gold and associated vein minerals were probably derived from the volcanic rocks and, to a less extent, from the adjacent granite, at greater or less but not extremely profound depths.

The concentration of the ore in veins was probably due largely to the influence of agencies generated in or near the volcanic rocks.

The vein minerals were carried into the fissures in solution and were deposited largely as a replacement of the country rock after the general alteration of the latter had progressed at least to a very considerable extent.

The deposition of ore in fissures may have been caused in part by a chemical reaction with the country rock, but it was probably due more to a chemical reaction with other solutions, assisted by other causes incident to the change in environment in the solutions as they rose along the fissures.

The localization of ore in shoots is due in some cases to a restricted circulation of ore-bearing solutions, guided by the more permeable places along fissures and by transverse fractures, and in other cases to a variety of other minor causes.



CLAIM MAP OF THE CRIPPLE CREEK DISTRICT.

the gold was deposited but also in other parts of the fissure, so that the result would be a well-defined vein with important quantities of gold in certain parts only.

It is a noticeable fact that where a fissure crosses a dike the latter often seems to influence the amount or, more rarely, the grade of the ore. The influence is usually on the amount, for in some of the softer dikes of the district the fissures are often narrower and not so well defined as in some of the other rocks, and hence here the effect is purely mechanical. Sometimes, however, the grade of the ore seems also to be affected, as is shown in the Eclipse mine, in which the best ore occurs near where the fissure intersects a dike. The influence of the dike in such a case as this may be because it is a manifestation of later eruptive action than the inclosing rock, and therefore waters rising along the part of the fissure cutting it may have been hotter and may have possessed greater chemical activity there than elsewhere along the fissure; or it may possibly be due to the fact that in such cases the rocks from which the waters rose contained more gold than occurred elsewhere; or that the dike contained better precipitants for gold than the surrounding rocks. Where a fissure follows a dike instead of crossing it, any influence that the latter may have is of course felt along the fissure throughout its course, as is seen at the Elkton and other mines.

In conclusion, it may be said that, except in a few cases, sufficient development work has not yet been done in the Cripple Creek district to clearly define the ore shoots; and, moreover, there is a reluctance on the part of many mine owners to give or to allow to be gotten sufficient data to determine the nature of the shoots in their mines.

SUMMARY.

The statements in this chapter may be summarized as follows:

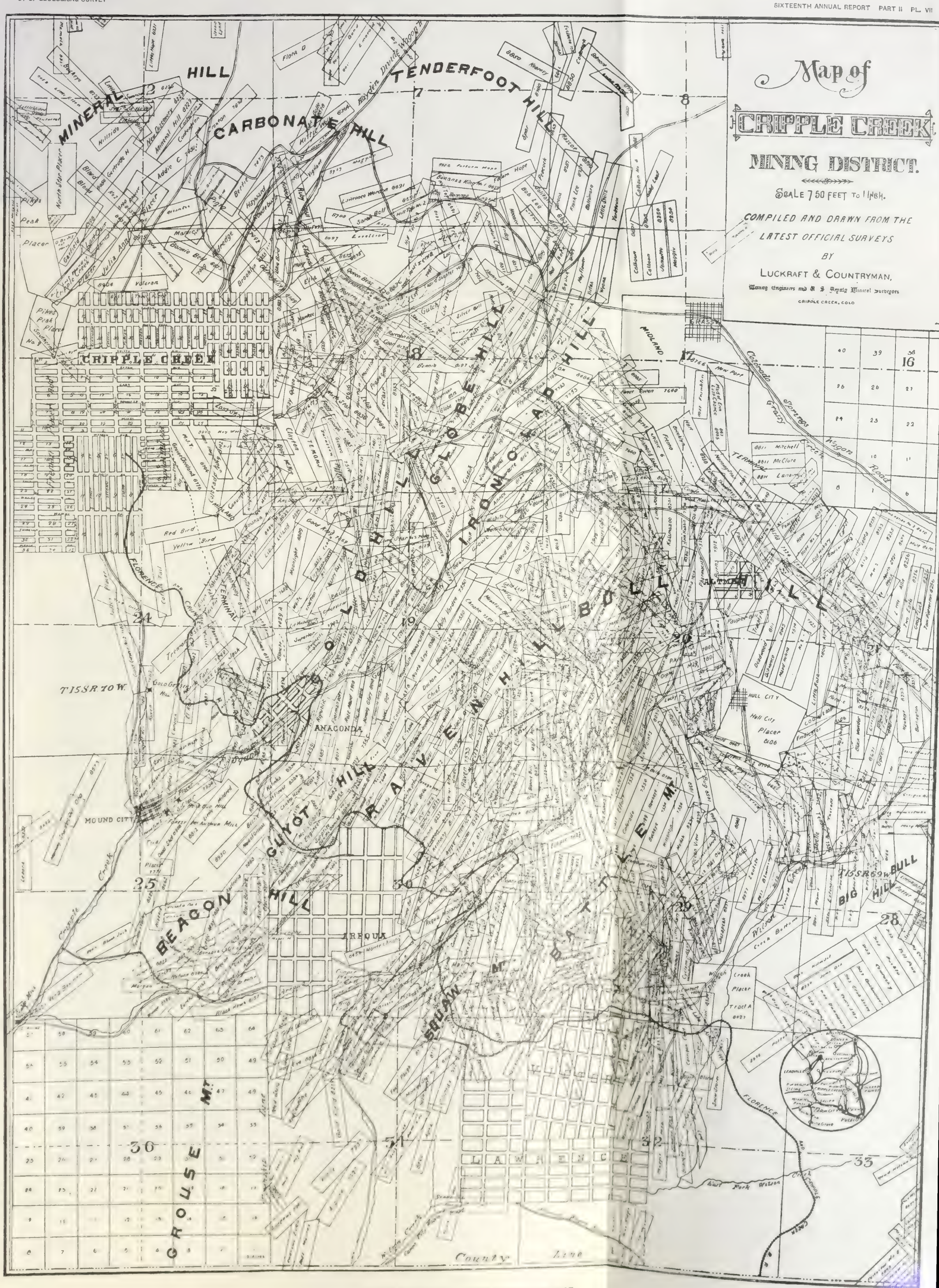
The gold and associated vein minerals were probably derived from the volcanic rocks and, to a less extent, from the adjacent granite, at greater or less but not extremely profound depths.

The concentration of the ore in veins was probably due largely to the influence of agencies generated in or near the volcanic rocks.

The vein minerals were carried into the fissures in solution and were deposited largely as a replacement of the country rock after the general alteration of the latter had progressed at least to a very considerable extent.

The deposition of ore in fissures may have been caused in part by a chemical reaction with the country rock, but it was probably due more to a chemical reaction with other solutions, assisted by other causes incident to the change in environment in the solutions as they rose along the fissures.

The localization of ore in shoots is due in some cases to a restricted circulation of ore-bearing solutions, guided by the more permeable places along fissures and by transverse fractures, and in other cases to a variety of other minor causes.



CLAIM MAP OF THE CRIPPLE CREEK DISTRICT.

CHAPTER V.

DETAILED DESCRIPTIONS.

GENERAL STATEMENT.

In this and the next chapter the general character of the ore deposits in the different parts of the district and the features which are especially characteristic of individual localities will be discussed. Particular mines will be described when they illustrate special points; but the details of every mine will not be given, because, in the first place, there are so many mines in the district that the details of all would necessitate an immense amount of repetition, which would be of no special use to anyone; and, in the second place, many mine owners do not wish the details of their mines to be made public. The general geology of different parts of the district has already been discussed by Mr. Cross, and it will be mentioned here only in so far as it concerns the ore bodies.

MINERAL, CARBONATE, AND TENDERFOOT HILLS.

General features.—The three hills known as Mineral, Carbonate, and Tenderfoot are in the northern part of the district. The principal placer deposits of the district are on the south slopes of Mineral and Carbonate hills, and as these placers were among the early sources of the Cripple Creek gold production, a large amount of the early prospecting for ore was naturally done on the hills in the immediate vicinity. As a result, therefore, a large number of claims were taken up on these three hills in the first year of mining at Cripple Creek, though the early paying mines were found in other parts of the district. A number of exploring shafts and tunnels were made and some ore was found; but the developments in other parts of the district were so much more encouraging than at this northern end that it was for a time almost abandoned, and but little attention was paid to it until the fall of 1894, when active prospecting again began, and recently ore has been found in a number of places. Among the principal claims on which important development work has been done on these hills are the New Discovery, Free Silver, Elk Horn, Emma Bland, Golden Terry, Contention, Bland, Addie C., and others.

A part of the area comprised in the three hills is in the region of breccia and a part in the granite.

POVERTY GULCH.

General features.—Poverty Gulch is on the northwest side of Globe Hill, and is the site of the first mine that became a regular producer of gold in the Cripple Creek district, i. e., the Gold King; but since then a number of other claims in this vicinity have been developed, the most noted of which is the C. O. D. mine. Among the other developments are the Chicago and Cripple Creek tunnel, and various smaller openings on the Rebecca, Jewel, Queen Bess, and other claims.

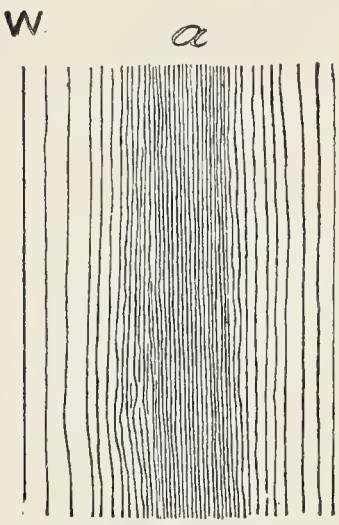


FIG. 10.—Section showing the mode of occurrence of ore in the C. O. D. mine. *a*, vein. Scale: 1 inch = 4 feet.

Gold King mine.—The Gold King mine is on what is known as the "El Paso" claim, and is worked from two tunnels penetrating the hillside for several hundred feet. The ore occurs in two veins which follow a very circuitous course. They consist of the country rock more or less replaced by quartz, iron pyrites, iron oxides, and other minerals, and they vary from a fraction of an inch to several feet in thickness. The gold occurs as both free gold and telluride of gold.

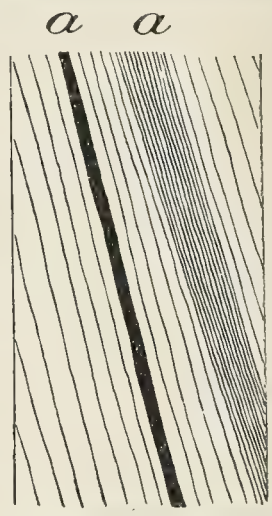


FIG. 11.—Section showing the mode of occurrence of ore in the C. O. D. mine. *a*, *a*, veins. 1 in. = 4 feet.

C. O. D. mine.—The C. O. D. mine is in Poverty Gulch, just opposite the Gold King, but on a totally different vein, and as it is remarkable in many respects, it will be described somewhat in detail. At the time the examination was made the main shaft was about 220 feet deep and was still being sunk. Three levels had been worked, at depths of 50 feet, 100 feet, and 150 feet, respectively, as is shown in fig. 15, page 170. The mine was opened on a vein striking from N. 10° E. to N. 25° E., dipping at angles of from 70° to 90° in an east-by-south direction, and varying from a few inches to 7 feet in thickness. The country rock is entirely an andesitic breccia, much altered, and, at a depth below immediate surface influences, hard and compact.

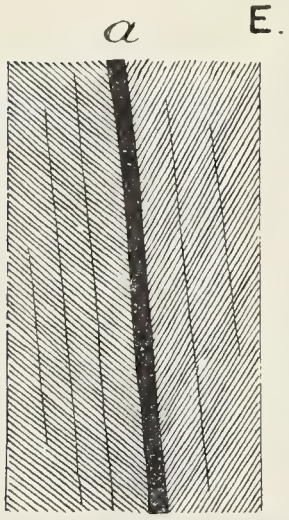


FIG. 12.—Section showing the mode of occurrence of ore in the C. O. D. mine. *a*, vein. 1 inch = 4 feet.

The ore occupies a well-defined fault fissure, with distinct grooves or slickensides on the walls and with numerous subordinate cracks on either side of the main fissure. The latter are so numerous as to give the rock a distinctly slaty structure, in which the cracks are sometimes

only a small fraction of an inch apart, though sometimes farther. This structure extends outward for from a few inches to 2 or 3 feet on each side of the main fissure, until the cracks become farther apart and less distinct, finally disappearing in the country rock on either side. Such a structure is evidence of the intense compression which has been exerted along the line of the fissure, and a very noticeable feature in it is that, instead of always being parallel to the main fissure, the sheeting sometimes runs off diagonally from it on each side at angles of from 1° to 45° or more. As this diagonal structure, however, passes in other places into the parallel structure, there can be but little doubt that it has been produced by similar forces, probably modified by local causes. Figs. 10, 11, 12, and 13 illustrate this subject.

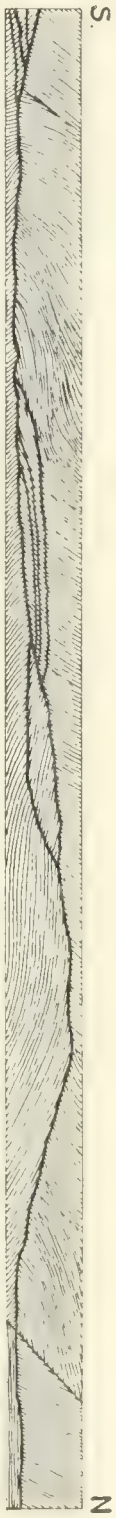


Fig. 13.—Horizontal plan in south drift, second level, C. O. D. mine, showing the main fissure and the subordinate fissuring. 1 in.—16 ft.

The main fissure is slightly faulted in several places in the mine; but the throw has nowhere been proved to be over a few inches, and the faults seem to have occurred before the deposition of the ore, for the latter is not cut off by them, but simply curves around on the fault planes and then continues in the original fissure. The cross faults often show a parallel fissure structure similar to that in the main fissure, but less distinctly marked, as shown in fig. 14.

The ore of this mine occurs along the main fissure and in the subordinate cracks on either side. It consists of the country rock impregnated and partly replaced by quartz, purple fluorite, iron pyrites, and iron oxides, and other materials in smaller quantities, among which is the telluride of gold, calaverite, of which an analysis is given on page 134. More or less red clay and fragments of country rock also occur in the ore. The calaverite has not been oxidized so deeply as in many places, and was found in its unaltered form even near the surface. The ore is high grade, the average of what has been shipped being over $100 per ton.

The ore occurs in a clear, well-defined shoot of very considerable dimensions. It has been continuous from the very surface to as great depths as have yet been reached, and has supplied large quantities of high-grade ore. It represents a part of the fissure or fissured zone where an unusual amount of ore deposition has occurred. In other words, it is a well-defined chimney of ore, formed in a manner not unlike that at the Anna Lee mine, on Battle Mountain. The course of the waters which deposited the ore, and consequently the form of the shoot, was evidently influenced by the cross fissures shown in fig. 15 and further discussed on pages 164–165.

Chicago and Cripple Creek tunnel.—This tunnel is on the southeast side of Poverty Gulch, a few hundred yards below the C. O. D. and Gold King mines. It penetrates a spur of Globe Hill for several hundred

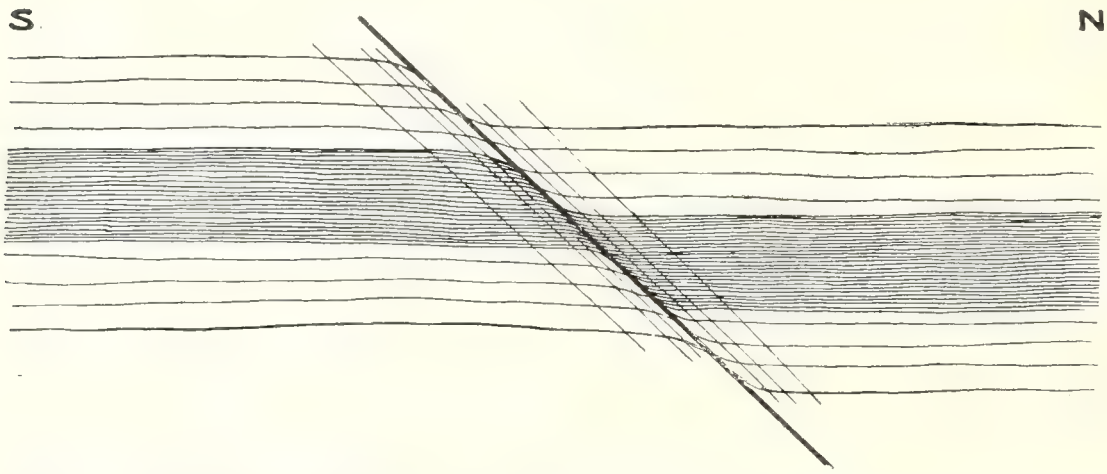


FIG. 14.—Horizontal plan in south drift, third level, C. O. D. mine, showing faulting of the ore-bearing fissures. Scale: 1 inch = 4 feet.

feet, and is still being extended. It is largely in breccia, though some massive rocks have been encountered. Several fissures, some of them carrying ore, have also been cut, but they have not yet been thoroughly

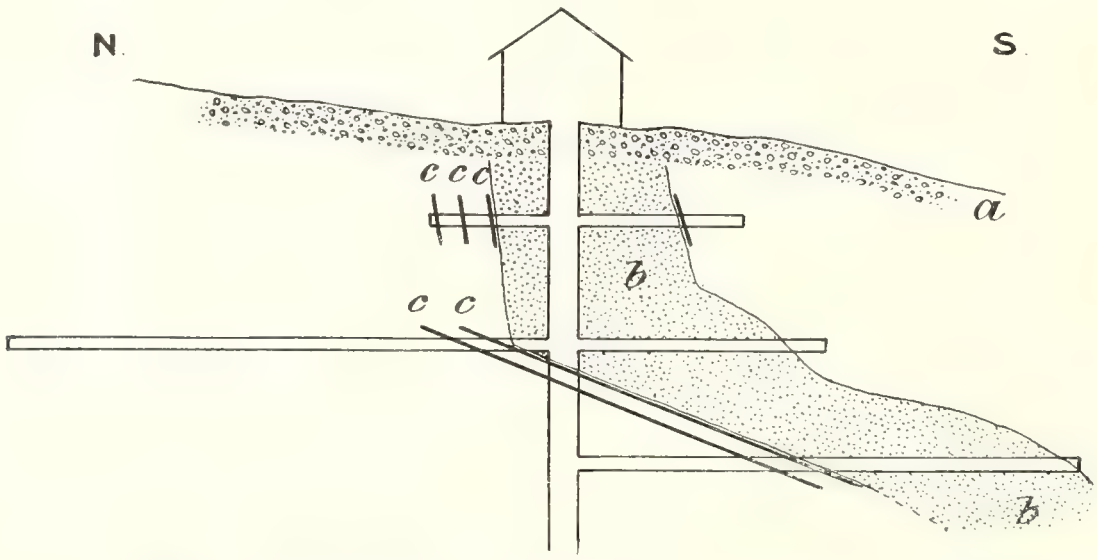


FIG. 15.—Longitudinal section in the C. O. D. mine, showing the mode of occurrence of the ore shoot. *a*, surface débris; *b*, ore shoot; *c*, cross fissures. Scale: 1 inch = 100 feet.

explored. A noticeable feature of one of these fissures is the presence of galena said to be rich in both gold and silver.

GLOBE HILL.

General features.—Globe Hill is northwest of Bull Hill, from which it is separated by Ironclad Hill. Numerous claims have been taken up in this part of the district, but the principal mines are the Summit and the Deerhorn. The Plymouth Rock claims, which are partly on

this hill and partly on Ironclad Hill, have been developed to a certain extent, and more or less work has been done on the Badger Boy, Pessimist, Bennie, and other claims. The hill is composed chiefly of volcanic breccia, cut by dikes and irregular bodies of eruptive rocks. Along certain zones the hill has been much fissured and often shattered by marked dynamic disturbances, and the rocks, especially the breccia, have been extensively altered and kaolinized. The ore occurs as well-developed quartz veins which represent the more or less complete replacement of the country rock along fissures, while outside of these veins the breccia is often sufficiently impregnated with gold to pay to work. The hill differs from other parts of the district in the fact that alteration and ore deposition have gone on along irregularly intersecting lines in a very wide zone of disturbance, instead of along parallel lines in a limited zone as elsewhere. Their general character will be best understood by a description of the Summit and Deerhorn mines.

Summit and Deerhorn mines.—These mines are near the summit of Globe Hill, on adjoining claims and on similar ore bodies, so they are treated together. The Summit mine consists of a shaft about 200 feet deep, with several subordinate shafts and numerous drifts. The extreme irregularity of the ore bodies has rendered the underground workings very devious, and many of the stopes and chambers have to be filled with square sets of timber to hold up the loose ground. The Deerhorn mine consists of a shaft 280 feet deep, with drifts at various levels and several subordinate surface openings. The workings are regularly laid out and follow only the more important bodies of ore.

These mines are in an area of breccia cut by massive rocks, which has been much fissured and broken, and often minutely shattered, and this disturbance has given every facility for the percolation and action of the heated waters that have affected this whole region. As a result the rocks have been greatly altered, softened, and impregnated with secondary minerals. The feldspathic constituents, especially in the breccia, have been converted to a pure, white kaolin,[1] which now forms a matrix for the larger or more resistant fragments of rock, or is concentrated into bodies of remarkable purity, often several feet in diameter. Besides this alteration of the rock, there has been a very extensive deposition of quartz, fluorite, manganese, and iron minerals, and other materials which comprise the ore. The quartz is sometimes white or rusty, but is often intimately associated with fluorite, forming the "purple quartz" characteristic of the district. The iron pyrites has usually been almost completely oxidized to such depths as have yet been reached, for the ground is loose and readily admits surface waters, thus permitting unusually extensive oxidation. In a vein on the 280-foot level of the Deerhorn mine considerable quantities of a compact, fine-

[1] For an analysis of this, see p. 128.

grained, crystallized gypsum, containing more or less fluorite, occur; while on some of the upper levels thin layers and crystals of gypsum are found in the cracks in the breccia. Among the rarer constituents of the ore may be mentioned lead, which is said to exist to the extent of 3 or 4 per cent in some of the Deerhorn ores.

The best-defined ore bodies occur in veins running in various directions. In fact, in some places the ground seems to be cut up by a network of such veins. Sometimes these veins are short and lenticular, at other times they are continuous for considerable distances, and they vary from a few inches to several feet in thickness. Though the ore occurs to a considerable extent in these veins, yet a large part of that mined is composed of the breccia more or less replaced by secondary minerals either along the sides of the veins or along independent fissures. The lines of disturbance in which these ore bodies occur represent together an extensive manifestation of the general fissuring that has affected the whole district, and it has often given the rock a minutely crumpled appearance, such as is seen in some of the Summit workings and on the Pessimist claim to the south. The zone of disturbance is confined within certain limits, but the exact boundaries of it are yet undefined by mining operations. It is, however, doubtless many feet in width, and probably has its longer axis in a direction somewhere between north and south and northeast and southwest, possibly approaching a direction somewhat east of north, though the individual fissures or veins in this general zone of disturbance often vary greatly from this course and sometimes strike almost east and west.

IRONCLAD HILL.

General features.—Ironclad Hill is just east of and really a part of Globe Hill, being separated from it only by a slight depression. A number of claims have been explored on this hill, but no very large amount of ore has been shipped. Among the claims are the Ironclad, Plymouth Rock, Wichita, Londonderry, Climax, Minnie Lew, American Girl, and others. The western part of the hill consists largely of volcanic breccia cut by dikes, while to the east and southeast the granitic fragments increase in quantity in the breccia, until on the eastern side of the hill, where it adjoins Bull Hill, the country rock is composed entirely of granitic breccia and more or less broken granite. Still farther east and south these materials pass into the solid granite of the central granite area. The granitic breccia has been much broken and disturbed by small faults, and in some places has been highly altered.

Ironclad mine.—The Ironclad claim is on the south slope of Ironclad Hill, and as it was one of the early claims developed in the district it gave the hill on which it is situated its name. It is not at present worked, but a shaft, now partly filled with water, is said to be about 80 feet deep. The ore occurs in a fissured zone, and is characterized by an unusually large amount of iron for this district. The iron

as now seen on the dump is largely in an oxidized form, but will probably pass into iron pyrites at a depth.

Plymouth Rock mines.—These comprise numerous small openings on the Plymouth Rock claims, which are partly on Ironclad Hill and partly on Globe Hill. Most of them show veins of quartz or fissures along which the country rock is more or less converted to ore. They strike in various directions and, in general mode of occurrence, are not unlike some of those described in the Summit and Deerhorn mines.

Minnie Lew mine.—The Minnie Lew claim is on the eastern part of Ironclad Hill and is developed by two shafts, the larger of them 150 feet deep, in a very much broken and shattered breccia. Numerous slight intersecting faults occur, and the rocks are sometimes more or less stained with iron. The mine is at present not worked.

In this same neighborhood are the Wichita, Londonderry, Climax, American Girl, and other claims, which are developed by small openings, mostly in the mixed granitic and volcanic breccia. This area is much broken and faulted and sometimes cut by dikes. Many of the openings are on veins in these faults, but others are simply in the more or less disturbed breccia in which the decay of the granite has given rise to seams of clay in the cracks. The Horseshoe mine is on Bull Hill, immediately adjoining Ironclad Hill, and is in a formation similar to that at the other mines just described.

GOLD HILL.

General features.—Gold Hill includes an irregular area lying southwest of Globe Hill. It was one of the early parts of the district to be explored, and numerous claims have been located on it. Among those on which considerable mining has been done are the Anaconda group of claims, including the Anaconda proper, Great View, Excelsior, and others, while more or less development work has been done on the Anchor claims, the Gold King,[1] City View, Lone Star Nos. 1 and 2, Coronada, Bonanza King, Temomj, and others.

Gold Hill is mostly an area of breccia, with numerous dikes and irregular bodies of massive eruptive rocks, though the eastern side is partly included in the granite area of the central part of the district. The breccia is much altered and has been converted to a hard, compact rock, but it does not show the great amount of kaolinization seen on parts of Globe Hill. The veins occur in fissures which are usually in the breccia, but which sometimes, especially in the Anaconda group of mines, the City View, and others, are partly in dikes and partly along the contacts of dikes with the country rock.

Anaconda group of mines.—The claims of this group were among the early locations in the district and extend from near the town of Anaconda northerly up the slope of Gold Hill for several hundred yards, following in the principal openings one general zone of ore deposition.

[1] Not the Gold King of Poverty Gulch.

Openings have not been made continuously throughout the whole of this distance, so that it can not be said with certainty that the various shafts are all on one single vein, but they are either on one vein or on approximately parallel and closely related veins. The principal openings are the Anaconda tunnels and shaft, the Great View shaft, and the Excelsior shaft. The main Anaconda tunnel runs in from the foot of the hill diagonally to the course of the vein for over 1,000 feet. A shorter tunnel higher up the hill also runs in diagonally to the vein, while a third one is on the vein. The last two are connected by a shaft. The principal vein follows irregularly along a dike and varies from a few inches to several feet in width. The ore consists of parts of the dike more or less replaced by quartz, iron pyrites, iron oxides, manganese oxides, fluorite, and other minerals in smaller quantities.

The Great View shaft shows much the same occurrence of ore as the Anaconda openings. The Excelsior shaft is 125 feet deep, with drifts at three levels.

Gold King mine.—The Gold King claim is near the summit of Gold Hill, and has been opened up at both its southeast and northwest ends. On the southeast a tunnel has been run in for over 300 feet on a narrow fissure in the breccia, containing more or less quartz, iron oxides, and telluride of gold, and striking in a general east-of-north direction. At the northwest end of the claim two small shafts have been opened on veins in the breccia running about N. 75° E. The ore consists of country rock, more or less replaced by quartz, iron pyrites, iron oxides, and other minerals, among which are free gold, telluride of gold, and small quantities of galena.

City View mine.—The City View claim adjoins the Gold King on the north and has been developed by a small opening near the shafts just mentioned on the Gold King. The ore occurs in a fissure in a phonolite dike and in similar fissures in the inclosing breccia. The dike strikes about N. 75° E. and dips about 70° north by west. The ore consists of the dike and the country rock more or less replaced by quartz and iron minerals.

Lone Star No. 2 mine.—This mine is near the summit of Gold Hill, and consists of a shaft about 50 feet deep, with short drifts on a quartz vein. The vein dips almost vertically, with a little inclination to the south, and is unusual in striking in a general direction N. 75° to 80° W. It is a well-developed body of quartz in a fissure in the breccia, and it alternately thins and thickens, varying from an inch to a foot or more in thickness.

In this same vicinity more or less work has been done on the Anchor claims, the Temomj, Bonanza King, Lone Star No. 1, Coronada, and other claims.

SQUAW GULCH.

General features.—Squaw Gulch starts on the slopes of Bull, Globe, and Ironclad hills, runs southwest between Gold Hill and Raven Hill, and drains into the valley of Cripple Creek. The town of Anaconda is

GOLD HILL AND ANACONDA RIDGE FROM THE SOUTHWEST.

The town of Anaconda in the foreground.

in this gulch, less than a mile above its mouth. A number of well-known mines occur along its course, but those which are on the slopes of the prominent hills are described under the headings of those hills, and only the claims on some of the small hills below Anaconda will be mentioned here. Among these are the Robert Burns, Blue Bell, Alexander, Caledonia, Alpha, Omega, and others, while the El Rino or Sweat mine occurs in a small parallel gulch just northwest of Squaw Gulch.

This lower part of Squaw Gulch is composed of granite cut by phonolite and other dikes, and it represents in part a portion of the rim of the volcanic materials which appear in the neighborhood of Anaconda. The zone of mixed granite and volcanic breccia, which separates the granite from the area of purely volcanic rocks, is well exposed on both sides of the gulch at and below the town. The ore occurs mostly in fissures in the granite or at the contact of granite with dikes, and more rarely in the granitic and volcanic breccia.

Blue Bell mine.—The Blue Bell claim is in Squaw Gulch, just below the town of Anaconda, and is developed by a tunnel several hundred feet long and some minor workings on a quartz vein intersecting the granite and the granite-breccia. The vein varies in strike in different places from almost due north and south to about N. 12° E., dips at from 85° to 90° to the westward, and varies from 6 inches to 3 feet in thickness. At the most southerly point at which it is exposed in Squaw Gulch it is in solid granite, more or less fractured by numerous cracks; but to the north the inclosing rock becomes more and more broken until it passes into a breccia of granitic and volcanic fragments. The ore, especially near the surface, is largely a rusty or gray quartz, but at a slight depth this passes into a mixture of purple fluorite and quartz with iron pyrites, manganese oxides, and occasionally some galena and sphalerite, which contain both gold and silver, as is shown by the accompanying assays, kindly furnished by the manager, Mr. J. S. Lentz.

Analysis of ore from the Blue Bell mine.

	Ounces per ton.	Per cent.
Gold	0.60	.....
Silver	62.50	.....
Lead	.....	8.50
Zinc	.....	18.30
Iron	.....	2.80
Silica	.....	45.00
Water	.....	1.15

The vein contains many fragments of granite and breccia broken from the walls and partially replaced by quartz. A remarkable feature of the mine is the large quantity of water encountered in it. Most of the mines of the district are comparatively dry and rarely require pumps, but a stream of water comes from the Blue Bell tunnel which has been used in running the Sylvanite Mill (ten stamps) and once supplied a part of the requirements of the Rose Bud Mill (fifty stamps).

Elsewhere in this part of Squaw Gulch more or less development work has been done on the Robert Burns and other claims.

Caledonia mine.—The Caledonia claim is on the northwest side of Squaw Gulch, about a half mile below the town of Anaconda, and is opened up by a shaft about 60 feet deep, with more or less drifting, and by several open surface cuts. The vein occupies a well-defined fissure in the granite, following the general course of a phonolite dike, but as the latter is extremely crooked the fissure sometimes comes in contact with it, at other times leaves it, and in one place at least crosses it directly. The vein strikes about N. 23° E. and dips at from 20° to 60° east by south. It varies from 1 inch to 3 inches in thickness, and is composed mostly of quartz with iron pyrites, iron oxides, more or less clay, and fragments of country rock. The gold occurs as both telluride of gold and free gold derived from the oxidation of the telluride. Much of the ore is extremely rich, often carrying several hundred or even several thousand dollars per ton. For a few inches on either side of the main fissure the granite is sometimes intersected by numerous parallel cracks, occasionally so close together that they give the rock an almost slaty structure. These cracks frequently contain thin films of quartz which carry more or less gold of lower grade than that in the quartz in the main fissure. Much of the rock containing these films is, however, shipped as low-grade ore.

The vein crosses the dike at the south end of the workings, and at this crossing it splits up into numerous thin, parallel fissures. Where it enters the granite again it forms one well-defined fissure and continues on in the same general direction, but is soon covered up by the soil on the slopes of Squaw Gulch. The course of the fissure lies in the direction of the St. Clair, Dead Shot, and Mary Nevin mines, on the other side of the gulch, and it is not improbable that these mines are on the same general zone of fissuring, though not necessarily the same individual fissure, as the Caledonia.

Lying to the northeast of the Caledonia mine are the Alexander, Alpha, Omega, and other claims, on which a small amount of work has been done on fissures in the granite striking from north and south to N. 25° E. The fissures are rusty and sometimes carry thin seams of quartz.

El Rino or Sweat mine.—The El Rino mine, also known as the Sweat mine, is on the El Rino claim, a few hundred yards north of the Caledonia mine, in a hollow almost parallel to Squaw Gulch. It consists of a shaft 160 feet deep, with a limited amount of drifting on a fissured zone in the granite containing ore in a series of parallel cracks. The ore consists of granite more or less altered and impregnated with quartz and iron minerals. The vein trends in a direction varying from north and south to about 25° east of north.

ROSE BUD HILL.

General features.—The name Rose Bud Hill is used here in the lack of a previous name for the hill immediately above the old Rose Bud Mill and lying between Squaw Gulch and Gold Run. Several claims have been located on this hill and a little development work has been done. Among them are the St. Clair, Dead Shot, Mary Nevin, Hibernia, and others. The hill is a part of the rim of the volcanic materials, and is composed of granite occasionally cut by dikes. The ore occurs in fissures in the granite, sometimes, though rarely, in association with dikes.

Dead Shot, Mary Nevin, and Hibernia claims.—These claims adjoin one another near the summit of the hill, on the southeast slope, and are on fissures in the granite. The Dead Shot and the Mary Nevin, and to a lesser extent the Hibernia, are developed by numerous small shafts and open cuts. The fissures strike in different places from N. 15° E. to N. 30° E. and dip about 80° in an east-by-north direction. They comprise a fissured zone consisting of one or more main breaks with numerous minor parallel fissures or cracks from 1 to 8 or 10 inches apart extending over a width of several feet. The openings on the three claims are in different places in this zone. The ore consists of the country rock impregnated along the fissures by quartz with iron and manganese minerals. The main fissures are partly filled with fragments of country rock and clay derived from the walls, and occasionally a very thin dike a few inches in width occurs.

The fissures have a general course in the direction of the fissures at the Caledonia, Alexander, and other mines on the other side of Squaw Gulch. The granite in both localities is intersected by a number of close parallel fissures for a width of many feet, and one of these may be the prominent fissure in one place, while another may be the prominent one in another place, so that several veins in different places may be on the same fissured zone without necessarily being in the same individual fissure. Such is probably the case on the Hibernia, Mary Nevin, Dead Shot, Caledonia, and Alexander claims, while the St. Clair claim, which is north of the Dead Shot, shows the same occurrences as those described on that claim and is probably also on the same general zone of fissuring.

BEACON HILL.

General features.—Beacon Hill forms the southwest end of a ridge running down from Raven Hill, and is separated from the main part of Raven Hill by Guyot Hill. A large number of claims have been located on it, and among those which have been most developed may be mentioned the Prince Albert, Great Mogul, Gold Dollar, Beacon, and Little May, while more or less exploration has been done on the Bonanza Chief and others.

Beacon Hill is composed on its lower slopes mostly of granite, cut by numerous phonolite dikes, while the top and upper slopes are composed of a solid mass of phonolite. In the present state of mining development on the hill it is impossible to say whether this mass is entirely an intrusive body forming a central core in the hill, or whether it is partly of this nature and partly an overflow. A portion of it, however, is shown to be an intrusive body, because in some of the mines and surface openings the lines of contact between the granite and the phonolite are very steep. It is not impossible that it may be an intrusive body which has partly overflowed, and from which the dikes on the slopes have emanated.

The ore occurs largely in fissures, partly in the granite and partly in the phonolite. The whole of Beacon Hill is cut by different systems of fissures, sometimes representing well-defined breaks, at other times only indistinct cracks. These systems intersect one another at various angles, and, so far as present developments show, there are two which are especially prominent, one running a little west of north and one running east of north. There are, however, many other small fissures running at various angles to these directions, and so far as has yet been found the ore is not confined to the fissures running in any one direction.

Prince Albert mine.—The Prince Albert and the Great Mogul are conflicting claims on the south slope of Beacon Hill, near the summit. The development work consists of a shaft 125 feet deep, with various irregular drifts and stopes. The mine was originally opened on a quartz vein in the gray granite, near the contact with the phonolite mass which comprises the summit of the hill. The vein strikes in a general northeast-and-southwest direction, and dips at from 80° to 90° southeast toward Arequa Gulch. At a depth of about 100 feet in the mine a phonolite dike was encountered, dipping into the hill at low angles, varying from 20° to 30°. The vein had been continuous from the surface down to this dike, but here it was represented simply by rusty streaks, which continued down through the dike. It was found that where the ore in the fissure met the dike the granite immediately overlying the dike had been considerably altered and in some places formed rich ore. In mining operations this ore was followed irregularly down on the dip of the dike for a few feet. Subsequent operations also proved the existence of a certain amount of somewhat similar ore in the granite immediately below the dike, but this has not yet been extensively developed.

The ore deposition in this mine has obviously progressed partly along the granite at its contact with the dike and partly in the fissure in the granite. The ore in the granite above the dike is not sharply defined from the main granite, but consists simply of this rock from which the mica has been removed, and which has been more or less replaced with quartz, iron pyrites, and other minerals. The granite along this contact is much shattered and is a good repository for these

minerals. The dike rarely contains any ore except immediately at its contact with a rich body of ore in the granite. The gold occurs mostly, if not entirely, in the form of the telluride, calaverite, an analysis of which is given on page 134. Some of the ore is of very high grade, while low-grade ore is also produced.

The Gold Dollar mine adjoins the Prince Albert, and, though it was inaccessible at the time the district was examined, the ore is probably not materially different in its mode of occurrence from that at the Prince Albert.

Beacon mine.—The Beacon claim adjoins the Prince Albert on the northwest, and consists of several small shafts and drifts on a vein occupying a fissure running in a general direction of N. 26° E., and dipping steeply. The openings are in several places along a distance of about 500 feet, and though they have not been proved by connected work to be on the same vein, yet they are either on one vein or on closely allied and parallel veins in the same general fissured zone. Many of the openings are now inaccessible, so that detailed observations are not possible. The vein varies from 1 inch to 4 inches in width, and is mostly in the phonolite mass which forms the upper part of Beacon Hill, though at the southwest end of the claim the vein passes into the granite. The ore consists chiefly of country rock impregnated with quartz, fluorite, and iron minerals, and carrying gold in the form of telluride or of free gold derived from the oxidation of the telluride.

A distinct fissuring in a direction approximately north and south, or west of north, crosses the main fissure in a number of places on this property. It is represented in some places by single cracks and in others by zones of parallel cracks, which occasionally, though rarely, carry ore. Elsewhere in the neighborhood the general fissuring of the hill is very evident.

Besides the mines already described, more or less development work has been done on the Little May, Bonanza Chief, and others.

GUYOT HILL.

General features.—Guyot Hill is between Squaw and Arequa gulches, and connects Raven Hill with Beacon Hill. Less development has been done here than in many other parts of the district, but a number of claims have been located and a few openings have been made. Among some of the best-known claims are the Camilla, Hobo, Engineer, and others. The hill is composed mostly of volcanic breccia, intersected by numerous phonolite dikes striking in a general course of north by east, but it includes also a part of the granite rim on its southwest end. The country rock is intersected by the fissures characteristic of the district, and is altered to an unusual degree. It is often soft and extensively kaolinized, very much in the manner of parts of Globe Hill. Frequently the rock has been largely converted to a mass of kaolin, carrying still undecomposed fragments of the breccia. The ore occurs in veins, sometimes following the dikes, sometimes in independent fissures.

Camilla claim.—This claim has been opened by two small shafts and numerous surface pits. The veins are either closely associated with dikes or are in their vicinity, and contain considerable quantities of mixed fluorite and quartz, but the best ore yet found is a mixture of quartz and iron pyrites.

RAVEN HILL.

General features.—Raven Hill adjoins Bull Hill on the west and southwest. It is one of the most important parts of the district, and many of the best-known mines are situated on it. Among the claims on which a considerable amount of mining has been done are the Raven, which was one of the first claims located in the district; the Princess, Gregory, Jack G., Ingham, Catherine, Elkton, Moose, Bertha B., Chief, Ida May, North Star, Dolly Varden, Morning Glory, Mattie D., and others; while among those which have as yet been less developed are the Rhinoceros, Free Silver, Something Good, Kentucky Belle, Eclipse No. 1, Rattler, Little Clara, Doctor, Nora H., Duke of York, and others.

The hill is composed largely of volcanic breccia cut by a great number of dikes and irregular intrusive masses of eruptive rocks. The dikes have a general course of from a little west of north to a little east of north, though sometimes they strike at various angles to these directions, and in some cases they approach more nearly to an east-and-west course; but as a rule a general northerly trend is distinctly observable. The ore occurs in fissures which were formed after the intrusion of the dikes, or sometimes in fissures which were formed previously and along which there was a further movement after the intrusion of the dikes. The veins occupying these fissures sometimes follow the dikes, sometimes cross them at low angles and are deflected along them for greater or less distances, as at the Raven mine, and sometimes cross them at high angles without any deflection, as at the Morning Glory and other mines. The veins on this hill show a much more marked tendency to be more or less closely associated with dikes than in most parts of the district, except on Battle Mountain, and many of the most important mines mentioned above are on fissures which follow dikes for a greater or less part of their course. This association of veins and dikes has already been discussed on pages 146–147, and the reader is referred there for further details on the subject.

Raven, Princess, Gregory, Jack G., and Ingham mines.—These claims are on closely allied ore bodies and are therefore treated together. They begin with the Raven, on the south slope of Raven Hill, and extend in the order named up the hill in a northerly direction almost to the summit. Their relative positions are shown in the accompanying map (Pl. X). The Raven claim is opened by a lower tunnel several hundred feet long, an upper tunnel about 800 feet long (which also extends on to the Princess claim), a shaft about 180 feet deep, connecting the upper tunnel with the surface, and numerous subordinate openings. The Princess claim is opened by one small shaft and several

RAVEN HILL AND AREQUA GULCH FROM THE SOUTHWEST.

surface openings, as well as by the extension of the upper Raven tunnel. The Gregory claim is opened by several small surface workings. The Jack G. claim is opened by a shaft 100 feet deep, with several drifts, as well as by numerous smaller openings. The Ingham claim is opened by a shaft 200 feet deep, with considerable drifting on three levels, as well as by a smaller shaft and surface pits.

A large part of the ore from all these claims is derived from veins in one main zone of parallel fissuring. The workings on the different claims are not connected, and they are not necessarily all on the same fissure; but there is very little doubt that they are all on a series of close parallel fissures, forming a fissured zone, in which one fissure may carry most of the ore in one place and another may carry most in another place. The evidence for this is that the various openings are on the same general line, and the veins in them have the same general strike and dip, are similar in the structure of the fissures they occupy, and are composed of much the same materials. The fissured zone as seen in the different openings varies from 1 foot to 10 and possibly sometimes 20 feet in width, and is composed of country rock intersected by numerous parallel cracks from a fraction of an inch to several inches apart. As a matter of convenience this zone of parallel fissuring, with its ore, will be spoken of collectively as the vein, though it really consists of numerous closely adjacent veins. It strikes at angles varying from about north and south to a few degrees east of north, though it has a general course of very nearly due north and south (see map, Pl. X), and it dips at angles varying from 60° to 80° to the west.

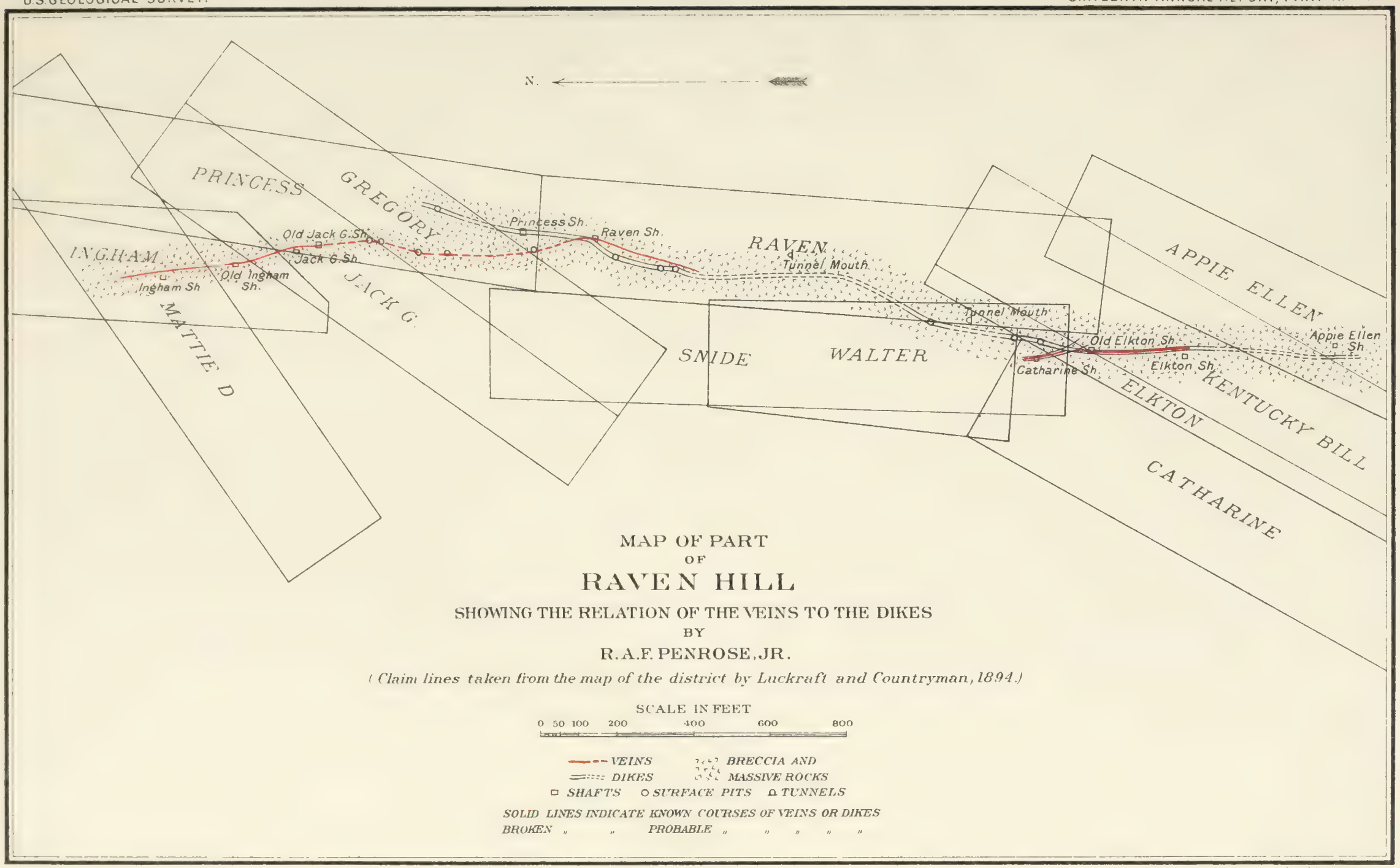
The ore consists of the country rock impregnated and more or less replaced along the parallel fissures with quartz, iron minerals, occasionally a little fluorite, and other materials. The gold is in the form of both free gold and telluride, the former probably being the oxidation product of the latter. The country rock is mostly breccia cut by numerous dikes and irregular masses of eruptive rocks. What is known as the Raven dike is the only one which has any special bearing on the present case. It varies from less than a foot to 5 or 6 feet in width, strikes in a general course of a few degrees east of north, dips steeply to the westward and is often vertical, while in one place it dips a very little to the east. It frequently thins out in a wedge and comes to an end, leaving an empty fissure, along which, farther on, it may appear again; while sometimes it reappears in a separate but closely adjacent and parallel fissure. In fact the dike seems to have been originally intruded into a much-fissured zone and to have come up along slightly different lines even in local areas. In several places, also, it forks and follows two diverging fissures, though one branch usually comes quickly to an end.

The zone of fissuring occupied by the dike and that occupied by the vein represent different lines of fracture and cross each other at low angles; but both fissures were formed before the intrusion of the dike,

as is shown by the fact that at the crossing of the fissures near the Raven shaft the dike throws out a fork for a few feet from the main dike along the vein fissure, thus clearly proving its later age. (See map.) There has, however, been a second movement along the vein fissure before the deposition of ore and after the intrusion of the dike in the other fissure, for a marked break, and sometimes a series of parallel breaks, containing ore clearly cuts the dike where the latter crosses the vein fissure. The vein dips in the same direction as the dike, but a little less steeply, and therefore south of the crossing it gradually approaches the latter as depth is acquired. At a depth of about 130 feet in the Raven shaft the vein meets the dike and follows it thence to just below the tunnel level (180 feet), where it leaves it and dips off on the west side of the dike. Fig. 16 illustrates this subject.

FIG. 16.—Vertical section in the Raven shaft, showing the relation of the vein to the dike. *a*, vein; *b*, dike. Scale: 1 inch = 50 feet.

As already said, most of the ore occurs in the main vein fissure or fissured zone, but as the dike also represents the course of a fissure, more or less ore occurs along it as well; and, in fact, the dike, on account of its more striking appearance, is usually called the "vein," and has been the object of by far the greater amount of work. The lower tunnel on the Raven claim follows this dike throughout most of its course, and occasionally a little ore has been found. The upper tunnel intersects the dike at about 250 feet from its mouth, and follows it thence in the same general way as does the lower tunnel. Ore has been found along the dike in this upper tunnel in several places, but the principal one is where the main vein, already described, crosses the dike on the tunnel level just south of the junction of the tunnel and shaft. Those who look on the dike as the vein, call this the main ore shoot, but the ore occurs here simply because the vein happens to cross the dike at this place. Another ore body on the dike is a little over 300 feet from the mouth of the tunnel, where a certain quantity of ore was found along a fissured zone at the contact of the dike and the country rock. Another place where ore occurs in the dike is about 120 feet north of the junction of the tunnel with the shaft, where for a dis-


N.
PRINCESS
GREGORY
INGHAM
MATTIE D
JACK G.
RAVEN
SNIDE
WALTER
APPIE ELLEN
KENTUCKY BILL
ELKTON
CATHARINE
Princess Sh.
Raven Sh.
Old Jack G. Sh.
Jack G. Sh.
Old Ingham Sh.
Ingham Sh
Tunnel Mouth
Tunnel Mouth
Old Elkton Sh.
Elkton Sh.
Catharine Sh.
Appie Ellen Sh.
MAP OF PART
OF
RAVEN HILL
SHOWING THE RELATION OF THE VEINS TO THE DIKES
BY
R. A. F. PENROSE, JR.
(Claim lines taken from the map of the district by Luckraft and Countryman, 1894.)
SCALE IN FEET
0 50 100 200 400 600 800
VEINS
DIKES
BRECCIA AND
MASSIVE ROCKS
SHAFTS
SURFACE PITS
TUNNELS
SOLID LINES INDICATE KNOWN COURSES OF VEINS OR DIKES
BROKEN " " PROBABLE " " " " "

tance of about 20 feet the dike and the immediately adjacent breccia have been very much kaolinized and impregnated with quartz and other minerals. It seems to be simply an area much more affected by the altering action of hot waters than other parts of the dike where kaolinization is less extensive, and it is not improbable that it represents the neck of a fumarole or hot spring, such as was probably common in the district at the time of ore deposition. (See p. 164.)

The main vein in the Raven mine has been explored to a depth of over 200 feet in the main shaft, and in a winze in the bottom of the upper tunnel, while elsewhere in small surface openings good ore has been shown to exist in the vein in many places. The extension of the vein is not opened on the surface from the Raven shaft to the pits on the Gregory claim, a distance of about 450 feet, but the underground workings of the Raven have traced thin seams of ore, probably representing the vein, northward to the Princess claim, thus leaving really only about 300 feet of unexplored ground. A number of small pits on the Gregory claim expose a vein which is directly in the course of the main Raven vein and is similar in the structure and character of the ore, so that there can be but little doubt that it is the same vein, or, as already explained, a part of the same fissured zone. The small pits on the Gregory claim show the vein to be situated, in part of its course at least, at the contact of the breccia and a white massive eruptive rock. This contact, being a line of easy fissuring, has locally guided the course of the vein fissure.

The Gregory openings show the course of the vein clearly up to the line of the Jack G. claim. Here the two shafts of the Jack G. mine and a number of small pits leave but little doubt that the vein worked on this claim is the same as that worked on the Gregory. On the Jack G. claim, however, the vein leaves the contact of the breccia and the massive eruptive rock, and is inclosed on both sides by breccia.

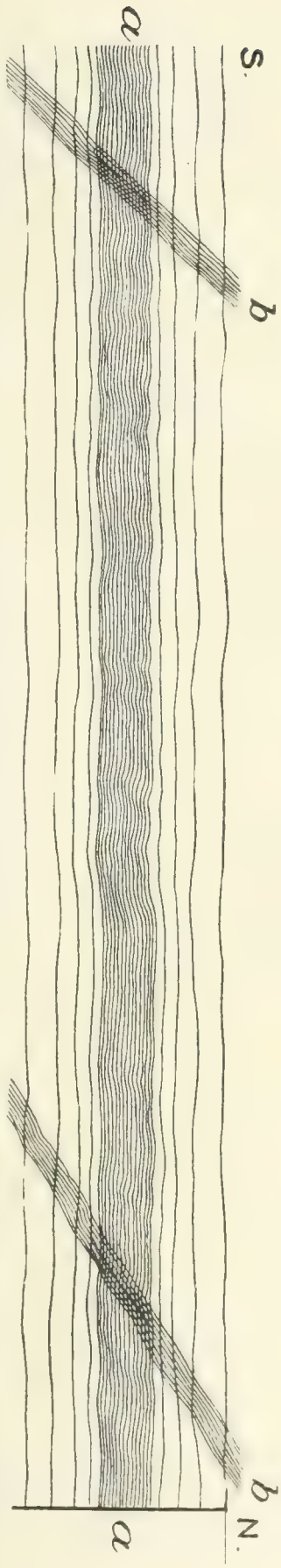


Fig. 17.—Horizontal plan in the south drift, first level, Ingham mine, showing intersecting veins. *a*, main vein; *b*, subordinate veins. Scale: 1 inch = 25 feet.

The course of the vein worked on the Ingham claim is clearly defined by the two shafts and the numerous surface strippings which have uncovered the vein almost up to the Jack G. line, so that there can be but little doubt that the vein here is simply the continuation of that on the Jack G., Gregory, Princess, and Raven claims. A noticeable feature in the Ingham mine is the presence of a system of fissures crossing the main fissures in a direction varying from N. 30° E. to N. 45° E. and dipping northwestward at various angles. Sometimes this fissuring is indicated by isolated cracks, but occasionally the latter are assembled into zones of parallel and closely adjacent cracks, which often but not always contain ore. The character and arrangement of the vein matter in each set of fissures at the intersections would indicate that ore deposition occurred in both at the same time. Fig. 17 shows the relation of the fissures. Another noticeable feature in the Ingham mine is the unusual width of the main fissured zone. Numerous parallel cracks sometimes occur for a width of from 10 to 20 feet, and from this the width decreases to much less. In the wider parts of the zone two or more positions are often marked by extensive ore deposition, giving the appearance of two parallel veins, and in some cases in the same cross-section both veins may be composed of quartz and other vein minerals, and may look identically the same, yet one may carry gold and the other may not. The occurrence of these parallel seams of ore is shown in fig. 18.

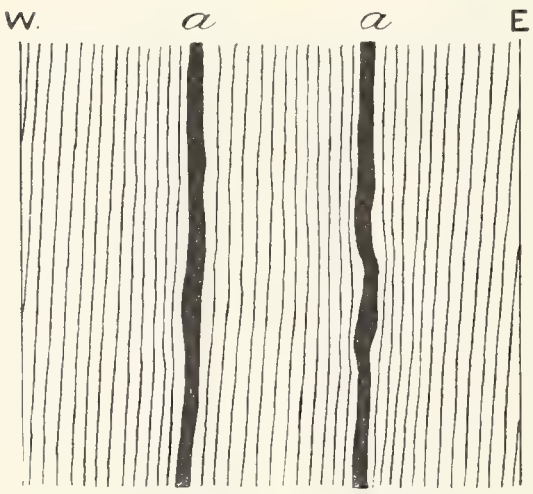


FIG. 18.—Section in the Ingham mine, showing the occurrence of parallel veins. *a*, *a*, veins. Scale: 1 inch = 10 feet.

A short distance southwest of the Ingham mine is the Mattie D. mine, which consists of a tunnel on a vein in the breccia, striking in a general northeast direction.

Elkton and Catherine mines.—The Elkton and Catherine claims are on the south slope of Raven Hill, just below the workings on the Raven claim (see map, Pl. X), and as they are closely related to each other in the occurrence of one of their ore bodies, they will be discussed together. The Elkton claim is developed by two shafts, one over 200 feet deep, the other 170 feet deep, and both are connected by underground workings. As seen by the map, much of the workings of the Elkton mine are on the Kentucky Bill claim. The Catherine claim is developed by a shaft over 100 feet deep and considerable drifting. A drift to the south connects it with one of the Elkton drifts, so that there is a continuous line of drifts from the north end of the Catherine workings to the south end of the Elkton workings, a distance of about 500 feet.

In these mines the ore occurs in association with two dikes, both of which are inclosed in the breccia. One of these dikes is the southerly continuation of the Raven dike, already described, and has supplied most of the ore in the Elkton workings; the other is an older dike, and has supplied all of the ore of the Catherine mine, as well as some of that of the Elkton mine. For the sake of convenience, the latter dike will be spoken of as the Catherine dike. The Raven dike strikes in a general direction varying from almost due north and south to a little east of north, and dips very steeply; the Catherine dike strikes a little west of north and dips almost vertically. They meet between the Catherine and the old Elkton shafts, and the Raven dike intersects the Catherine dike, as shown in the map, Pl. X. The ore in both dikes occurs in veins following the general courses of the dikes and composed of the rock more or less replaced by iron pyrites, iron oxides, quartz, and sometimes a little fluorite and other minerals, with gold in the form of free gold and telluride.

FIG. 19.—Section in the Elkton mine, showing relation of the vein to the dike. *a*, vein; *b*, dike; *c*, country rock. Scale: 1 inch = 4 feet.

The Catherine dike in the Catherine mine varies from 2 to 4 feet in width, and the ore from a few inches to a foot or more. To the south the dike widens, and in the Elkton mine it is often 10 feet or more in thickness, though in this mine most of the ore has come, not from this dike, but from the Raven dike, which has been explored for a distance

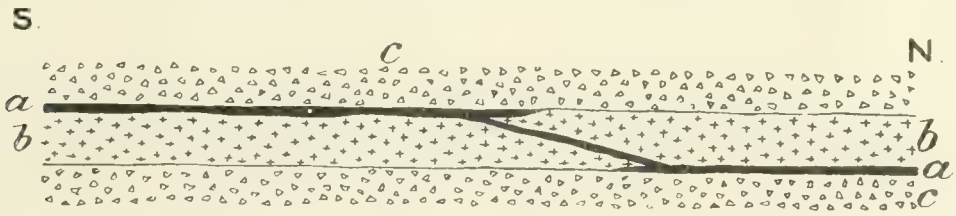


FIG. 20.—Horizontal section in the Elkton mine, showing the relation of the vein to the dike. *a*, vein; *b*, dike; *c*, country rock. Scale: 1 inch = 15 feet.

of several hundred feet along the drifts. The ore varies from a few inches to a foot or more in thickness and generally adheres to the contact of the dike and the country rock, as shown in fig. 19, though it frequently crosses and recrosses the dike from one side to the other. Where the ore leaves either side of the dike and crosses to the other side it often forks and continues along the abandoned side of the dike for a few feet, finally thinning out and disappearing, as shown in fig. 20. Sometimes outside of the main vein the dike is more or less broken by joints intersecting it in various directions, and in some places these

are often lined with a film of iron pyrites and telluride of gold, thus converting the whole dike into a mass of ore.

Moose mine.—The Moose claim is on the south side of Raven Hill, east of the Raven claim, and is developed by a shaft about 400 feet deep with a large amount of drifting to both the north and south. The vein follows the general course of a dike in a manner not unlike that already described at the Elkton mine. The dike strikes in a direction varying from N. 6° W. to N. 21° W., and dips on an average of 81° east by north. The country rock is mostly breccia, though the dike also intersects an irregular body of massive eruptive rocks in the northern part of the mine. The dike seems to occupy a much fissured and shattered zone in the country rock, and sometimes it forks, one branch following the main course, the other following a diverging fissure and quickly coming to an end. The main dike also occasionally thins, and sometimes disappears altogether, leaving an empty fissure.

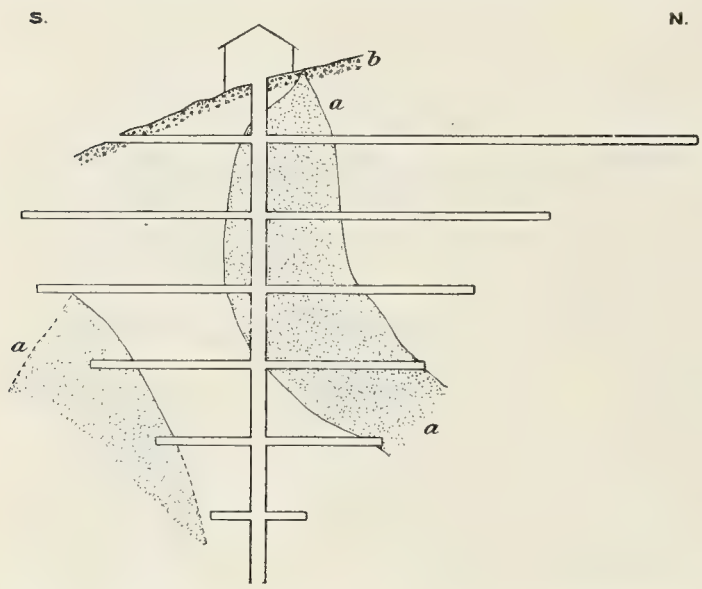


FIG. 21.—Longitudinal section in the Moose mine, showing the mode of occurrence of the ore shoots. *a*, ore shoots; *b*, surface débris. Scale: 1 inch = 200 feet.

The ore is at and near the contact of the dike with the country rock, and consists of the rock more or less replaced with iron minerals, a little quartz, and occasionally other materials. Sometimes the ore occurs on one side of the dike, sometimes on the other, and sometimes on both sides, in layers from an inch to a foot or more in thickness; while in places the central part of the dike contains more or less ore in the joint cracks, so that sometimes the whole width of the dike can be mined as ore. The gold occurs principally in the form of telluride, though near the surface it was probably, in part at least, in the form of free gold. It is not uniformly distributed along the dike, but occurs in more or less isolated shoots, as shown in fig. 21.

Bertha B. mine.—The Bertha B. claim adjoins the Moose on the north, and has been developed by an exploratory shaft 200 feet deep, with drifting on three levels. The work has been done on a dike in all respects like that in the Moose mine, and it is either the extension of the same dike or it is another dike close to where the extension of the Moose dike ought to pass. The dike has often a very circuitous course, and thins and thickens in the same manner as at the Moose. It is possible that there may be an interval in which the dike thins out and

disappears between the north end of the Moose workings and the south end of the Bertha B. workings, for the dike in both mines gradually becomes very thin toward this undeveloped intervening area. As yet the ore in the shaft and drifts has proved to be of low grade, but some rich ore has been found in a new opening to the north of the shaft.

The Kentucky Belle claim is east of the Bertha B., and is developed by a small shaft on a dike approximately parallel to that at the latter mine. Still farther east, on the slope of Bull Hill, adjoining Raven Hill, is the Ben Harrison claim, which is developed by a shaft 100 feet deep on a dike not unlike that at the Moose, striking in a general direction of N. 20° W. and dipping steeply, while near by is the Trail tunnel, which penetrates Bull Hill for several hundred feet and cuts a number of similar dikes. In fact, in this neighborhood, on both Raven and Bull hills, numerous dikes of this kind occur, trending in the same general direction, sometimes carrying ore and sometimes barren. Those on Bull Hill are mentioned here on account of their similarity to those on the adjoining part of Raven Hill.

Chief mine.—The Chief claim is near the summit of Raven Hill, and is developed by a shaft about 135 feet deep with a limited amount of drifting. The ore occurs in more or less close association with two intersecting dikes in the breccia, one striking approximately north and south, and the other a little north of west and south of east. Much of the ore is composed of the mixture of quartz and fluorite known in the district as "purple quartz."

Rhinoceros mine.—The Rhinoceros claim is northeast of the Chief, and is developed by a small shaft now closed, on a body of ore the best of which consists largely of loose, incoherent quartz commonly called "sand quartz."

This part of Raven Hill is composed of breccia literally honeycombed by a network of dikes and irregular masses of eruptive rocks; and numerous ore deposits, some in the breccia and some in the massive rocks, have been worked to a small extent. Among the claims in this locality on which more or less mining has been done are the Something Good, Free Silver, Duke of York, and others.

Ida May mine.—The Ida May claim is on the summit of Raven Hill, and has been developed by a shaft about 200 feet deep and considerable drifting, besides numerous surface openings. The work has all been done along a dike which intersects the breccia and possibly some massive rocks in a general N. 20° E. direction and dips almost vertically. The ore occurs at the contacts of this dike with the country rock, generally in the dike, but sometimes partly also in the inclosing rock; and it consists of either rock, more or less impregnated with iron minerals and quartz.

In the neighborhood of the Ida May mine numerous openings have been made in the breccia on veins and on fissures more or less impregnated with ore. Sometimes the ore is associated with dikes, but

in most cases it is simply in the breccia. Among the claims on which such openings have been made are the Little Clara, the Rattler, the Eclipse No. 1, and others.

North Star mine.—The North Star claim is on the western slope of Raven Hill, and is developed by a shaft 116 feet deep and a little drifting on a dike in the breccia, striking from N. 14° E. to N. 45° E., dipping almost vertically, and varying from 2 to 4 feet in thickness. The ore occurs in a series of parallel fissures which pervade the whole dike and the wall rocks, but which, along a certain narrow belt of a few inches in width, are closely assembled in a minutely fissured zone that varies in position in the dike, as shown in fig. 22. The ore consists

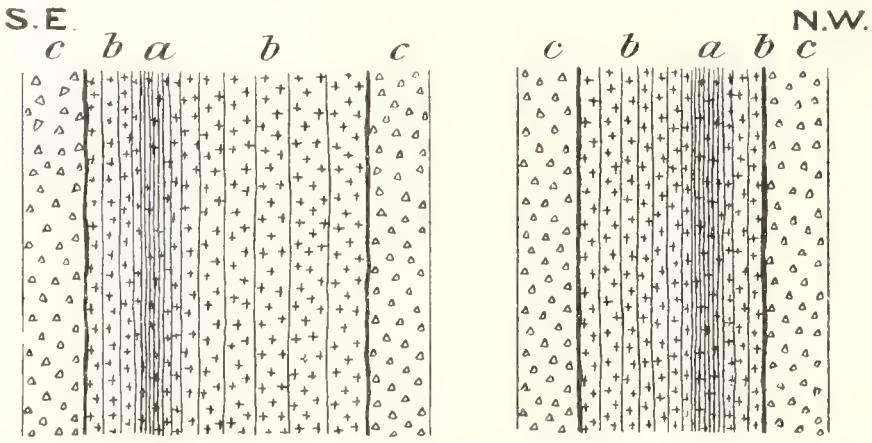


FIG. 22.—Sections in the North Star mine showing the relation of the vein to the dike. *a*, veins; *b*, dikes; *c*, country rock. Scale: 1 inch = 4 feet.

of the rock more or less replaced by iron pyrites, iron oxides, quartz, and other minerals.

Dolly Varden mine.—The Dolly Varden claim is on the northwest side of Raven Hill, in Squaw Gulch. At the time it was examined development work had only just begun, so that but few details can be given here. The claim at that time was worked in an open cut on a zone of parallel fissures in the breccia, which along these cracks was more or less replaced by iron minerals and quartz, forming an ore often very rich in gold. What appears to be the same ore-bearing zone has also been discovered on the adjoining Mountain Monarch claim and has produced a considerable quantity of ore.

Just below the Dolly Varden mine, in Squaw Gulch, is the Gold Standard tunnel, which penetrates the breccia and massive rocks of this side of Raven Hill for a distance of several hundred feet.

Morning Glory mine.—The Morning Glory claim is on the northwest slope of Raven Hill, in Squaw Gulch, just above the town of Anaconda. It belongs to the Work group of properties, and has been developed by a tunnel several hundred feet long and numerous surface openings on a vein striking in a somewhat irregular course west of north and dipping at from 60° to 80° to the south of west. It varies from a few inches to a foot or more in thickness, and where it is richest it consists of the mixture of quartz and fluorite locally known as "purple quartz."

The gold occurs mostly in the form of telluride, though sometimes as free gold also, and is most abundant in the parts of the vein containing fluorite. The vein occupies a well-developed fissured zone consisting of the country rock intersected by a number of parallel and closely assembled cracks. In some places the country rock in this zone is completely replaced by quartz and fluorite, while in other places but little of these minerals is present, though more or less iron occurs in the cracks throughout.

The country rock is mostly breccia, though several phonolite dikes occur in the neighborhood, and some of them are cut by the vein. Besides the fissured zone occupied by the vein, there is also a less distinct fissuring throughout the country rock, intersecting the main fissure in a general northeasterly course.

Near the Morning Glory mine are numerous other claims with small openings, among which are the Ida B., the Doctor, and others.

Mary McKinney and Republic mines.—The Mary McKinney and Republic claims are on the slope of Raven Hill and adjoin each other just above the town of Anaconda. They are both on the same vein, which is developed by small pits and tunnels along a distance of about 500 feet. The vein strikes about N. 20° to 25° E., dips almost vertically, and is largely in the breccia. It varies from 1 foot to 3 feet in width, and consists of fluorite and quartz in the intimate admixture known as "purple quartz," though near the surface the fluorite has been more or less leached out, leaving a granular mass of quartz stained brown by the oxidation of iron pyrites. Occasionally the vein forks and forms numerous thin parallel bands of ore.

CHAPTER VI.

DETAILED DESCRIPTIONS.—Continued.

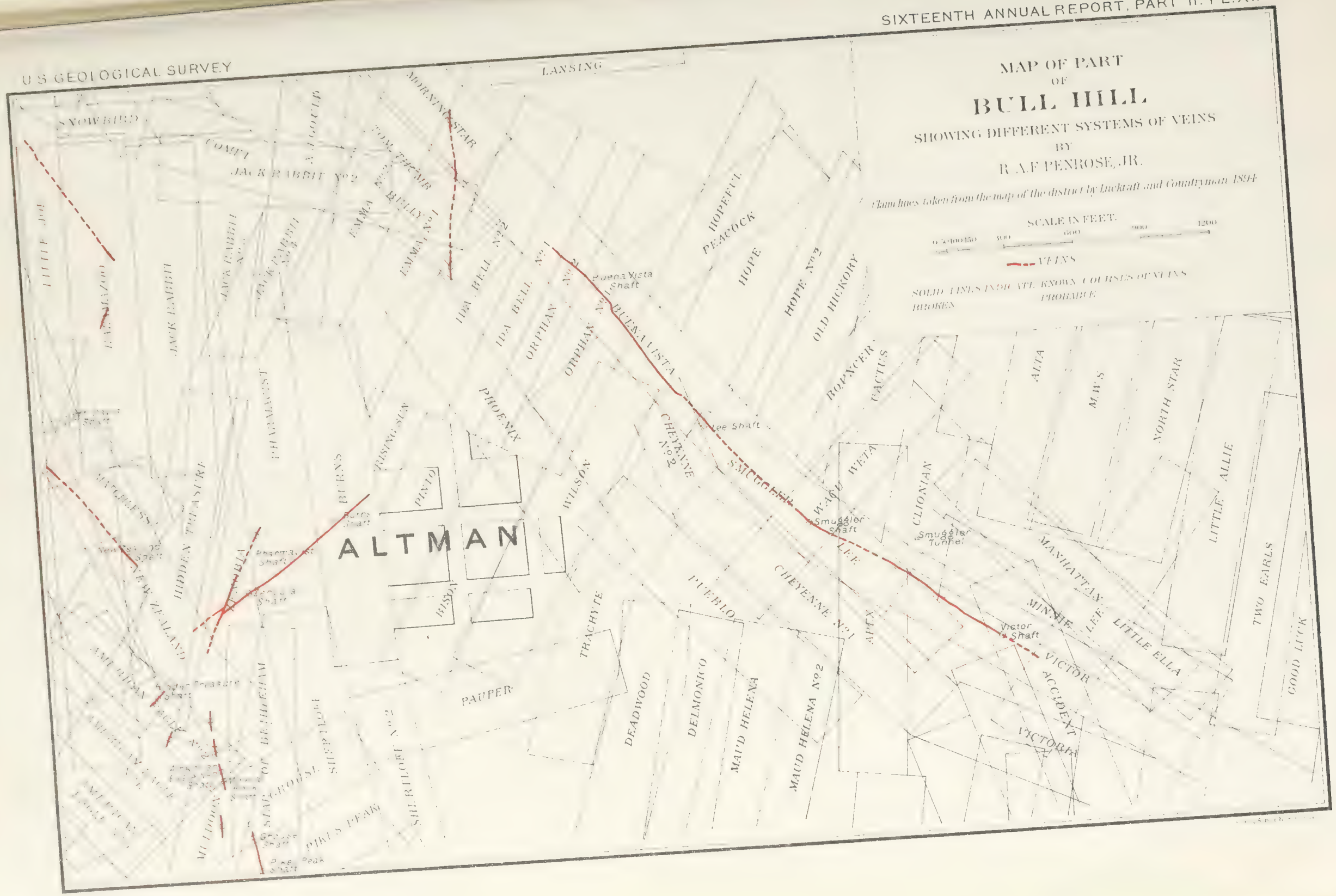
BULL HILL.

General features.—Bull Hill adjoins Raven Hill on the northeast, and is the highest part of the Cripple Creek district. Some of the most extensively developed mines in the district are located on it, and from the early days in the history of Cripple Creek it has been a prominent producer. The town of Altman occupies a position near its summit at an elevation of 9,500 feet. Among the claims on which a considerable amount of mining has been done are the Victor, Buena Vista, Smuggler, Lee, Pharmacist, Burns, Zenobia, Pikes Peak, Grouse, Orpha May, Blue Bird, and others, while among the claims on which less development has been done are the Lottie, Favorite, John A. Logan, Wolftone, Ben Harrison, Legal Tender, Longfellow, Lafayette, Specimen, Jeff. Davis, Wallace, American Eagle Nos. 1, 2, and 3, Horse Shoe, Trail, Ida Bell No. 2, Morning Star, Kalamazoo, Little Joe, New Zealand, Little May, and others.

Bull Hill consists of Bull Hill proper and Bull Cliffs, the former comprising the main part of the hill and the latter being the high eruptive knob on the eastern extremity, overlooking the Victor, Smuggler, and Little May mines. The higher parts of both Bull Hill proper and Bull Cliffs are composed of massive eruptive rocks, mostly phonolite and trachyte, already described by Mr. Cross; while the breccia, characteristic of the other parts of the district, occurs on the slopes of the hills, and in the sag between Bull Hill and Bull Cliffs. The extreme northwestern part of the hill is comprised in the central granite area of the district. All these rocks are indiscriminately cut by numerous dikes. Bull Hill differs from the neighboring hills in the unusually large size of its bodies of massive eruptive rocks, while the other hills consist largely of breccia with somewhat similar though smaller bodies.

Most of the important mines on Bull Hill are on veins in the massive eruptive rocks, though some few well-known mines, notably the Victor, are on veins in the breccia. Many of the veins occupy well-defined fissures representing fault planes, and often containing considerable quantities of fragments of country rock broken from the sides of the fissures. In no other part of the district is there more clear evidence of faulting than in some of these Bull Hill fissures, and this is probably due largely to the fact that the massive rocks of Bull Hill are brittle and easily fractured.

U.S. GEOLOGICAL SURVEY



Most of the noted vein fissures occur independently of dikes, and though occasionally there is some connection between the two, the close association of veins and dikes which is characteristic of parts of Raven and other hills holds true in only a few cases on Bull Hill. The veins are extremely numerous, and trend in various directions, though a general northwesterly, northeasterly, and an approximately northerly course are the most prominent. The accompanying map (Pl. XI) shows the relation of the different systems of veins, though only the more prominent veins are shown. The veins vary from a fraction of an inch to several feet in thickness, and are often well-defined bodies of quartz containing more or less iron pyrites, iron oxides, manganese oxides, fluorite, and other minerals, and often forming the cement of the fragments of country rock which occur in the fissures. Elsewhere the ore consists of the country rock more or less impregnated with these minerals along fissures.

Victor, Smuggler, Lee, and Buena Vista mines.—These mines are on the same vein or on closely allied veins occupying the same zone of parallel fissuring, and they are, therefore, treated together. It is one of the most thoroughly explored areas in the Cripple Creek district and has produced much ore. The two deepest shafts on the vein are the Victor, which is 350 feet deep, and the Buena Vista, which is 225 feet deep, with a large amount of drifting and stoping at different levels in both of them, while the Lee is developed by a shaft 80 feet deep, and the Smuggler by a shaft 105 feet deep and by a tunnel.

The workings in the Smuggler tunnel, which is on the southeast end of the Smuggler claim, connect with those of the Victor, so that the vein here is proved to be the same in both cases, and has been opened by drifts in both workings, but chiefly on the Victor, for a distance along the vein of over 1,100 feet. At the other end of this group of mines the underground workings of the Buena Vista are almost connected with those of the Lee shaft, so that the vein here also is practically proved to be the same in both cases, and has also been opened by drifts in both mines, but mostly in the Buena Vista, for a distance along the vein of over 1,100 feet. The Buena Vista and Lee drifts reach to within less than 1,000 feet of the Victor and Smuggler tunnel workings, so that this is the only stretch in which the continuity of the vein has not yet been proved. Intermediate between these two groups of workings, however, is the Smuggler shaft, on a vein in every respect like that in the mines on either side. In order to connect the Victor and Smuggler tunnel workings with the Buena Vista and Lee workings, it is necessary for the vein to make a slight curve, as will be seen on the accompanying map, and a curve which would throw the vein around in exactly the right position is seen in the Smuggler shaft. With the exception of this one turn, the workings in the various mines are along one general course, the physical character of the vein and the fissure is much the same in all, and the ore, though varying slightly in mineralog-

ical character, and being in some places rich in gold and in others poor, changes but little in nature from one end to the other. In all probability, therefore, the Victor, Smuggler, Lee, and Buena Vista mines, though all their workings may not be on the same individual body of ore, are at least on the same zone of fissuring and ore deposition, and if some of the ore bodies are on different lines at all, they are on parallel and very close ones. It may be added that in the Victor mine two closely parallel veins are worked.

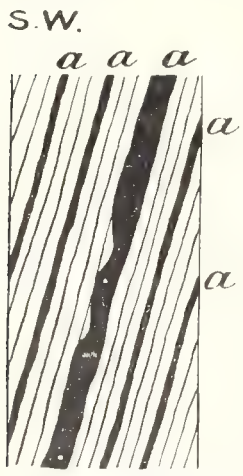


FIG. 23.—Section in the Victor, Smuggler, Lee, and Buena Vista vein, showing the mode of occurrence of the ore. *a*, veins. 1 in. = 4 ft.

The fissuring in the different mines is sometimes manifested by one clean-cut break, at other times by a series of parallel fissures, so that where these fractures become filled with ore either one well-defined vein or a series of closely parallel veins, grouped together in a width of only a few feet, is formed. The single fissures may fork and pass in different places into the group of parallel fissures, while possibly they may combine farther on in one fissure again, so that they can not be looked on in any other way than as forming one general zone of ore deposition. Where the vein occurs in one well-defined body, numerous fragments of country rock broken off during the formation of the fissure are often found in the ore. Occasionally the course of the ore-bearing fissures is locally deflected by preexisting fissures, as shown in the third of the accompanying figures (23, 24, and 25), which illustrate the different modes of occurrence of the ore.

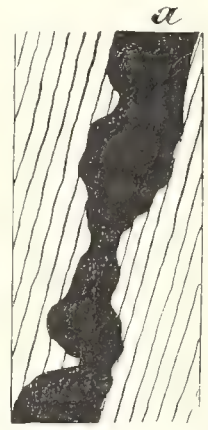
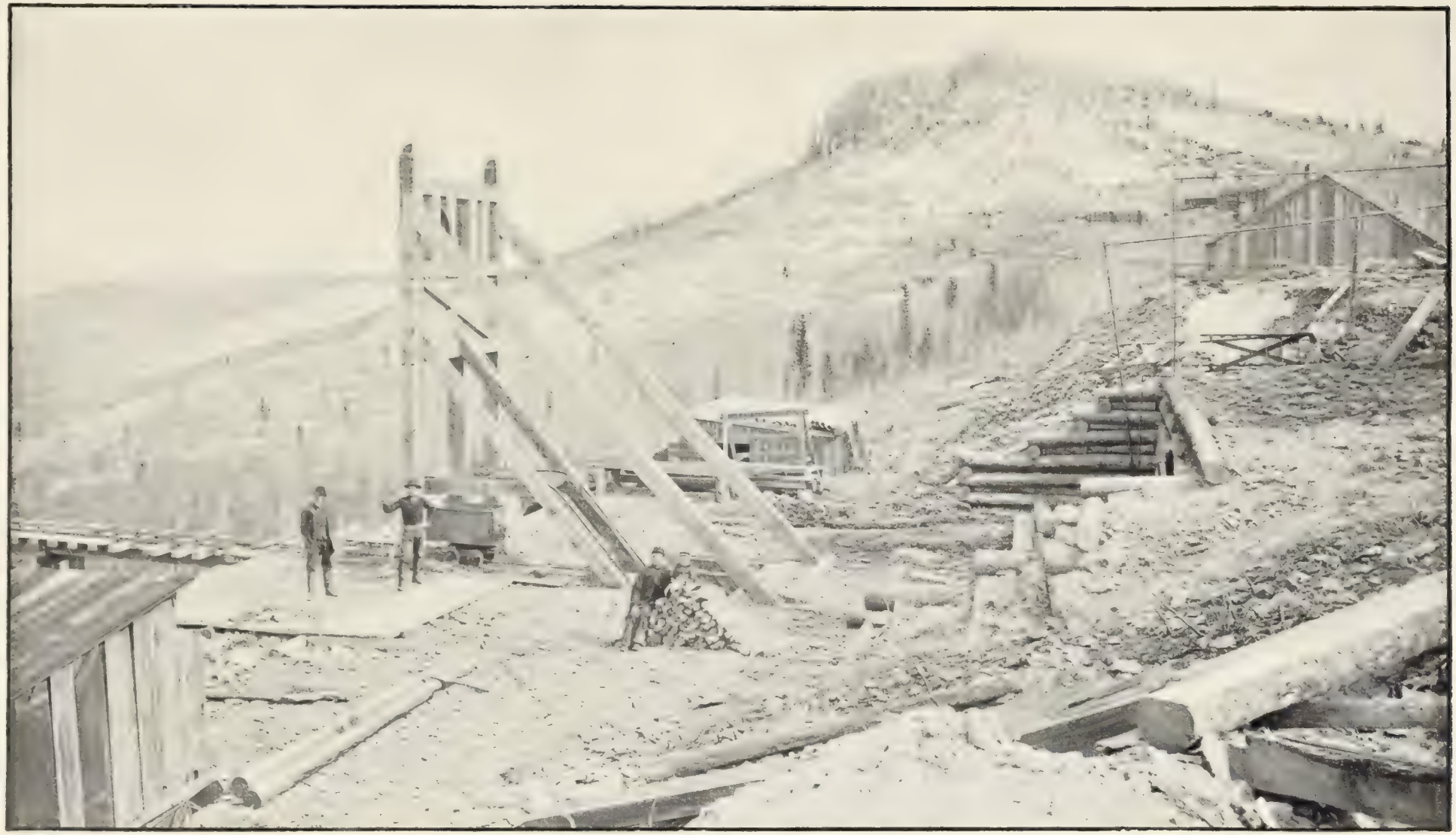


FIG. 24.—Section in the Victor, Smuggler, Lee, and Buena Vista vein, showing the mode of occurrence of the ore. *a*, vein. 1 in. = 4 ft.

FIG. 25.—Section in the Victor, Smuggler, Lee, and Buena Vista vein, showing the mode of occurrence of the ore. *a*, veins. 1 in. = 4 ft.

This main vein has a general northwesterly course, though it is often very circuitous and locally deviates very much from this general trend. It dips at angles ranging from 45° to 90° to the southwest in a manner as irregular as its strike, and varies from a few inches to 2 or 3 feet in thickness. Its circuitous course may be due in some cases to the irregular manner of fracturing, but it is probably also due partly to the fact that previous to the formation of the main fissure the country had been subjected to a general fissuring, running in a direction diagonal to the main fissuring, which constantly deflected the course of the latter in the manner described on page 148. This idea was suggested by Mr. Francis Freeland, manager of the Buena Vista mine, to explain



BULL CLIFF FROM THE BUENA VISTA MINE.

the sharp turns in the strike of the vein at that mine, and a similar cause would explain the irregularity in dip as shown in fig. 25.

The map (Pl. XI) shows the general course of this vein and its relation to the other principal veins on Bull Hill.

The country rock of the vein is partly massive rock (trachytic phonolite) and partly breccia. The part of the vein opened up in the Buena Vista workings and in the Lee shaft, as well as in part of the intermediate area, is all in the massive rock, but to the southeast the vein passes out of this rock, and on the Smuggler and Victor claims the country rock is breccia. This rock is comparatively hard in the Victor and Smuggler workings, but still farther southeast it passes into a soft, tufaceous breccia, in which the fissure is but poorly defined. The extension of the vein to the northwest of the Buena Vista workings has not yet been clearly determined.

In the Buena Vista mine the fissure which carries the ore has in one place been thrown by a lateral fault for about 20 feet, and a dike now occupies this fault plane. The faulting and the intrusion of the dike seem to have occurred before the formation of the vein in the fissure, for more or less ore deposition has also taken place in cracks in the dike at the points where the disconnected ends of the vein abut upon it.

The ore of the mines in question is composed essentially of quartz, with more or less iron oxides, iron pyrites, manganese oxides, fluorite, and other minerals in smaller quantities generally mixed with white kaolin or impure, rusty clay. Occasionally the quartz passes into a hydrous form of silica commonly called "jasper" by the miners. This is of a white, yellow, dun, black, or brilliant red color, and is especially abundant in the Victor mine, though it also occurs in the Buena Vista and other mines on this vein. An analysis of it is given on page 127. None of these mines have yet reached below the limit of very active oxidation, so that the manganese and most, though not all, of the iron are in the oxide forms. The gold probably occurs largely in the free state, though it is usually in a condition of such fine subdivision as to be invisible to the naked eye. Occasionally, however, some of it occurs as telluride. The rich ore is in more or less well-defined shoots, which are frequently continuous for considerable distances along the strike of the vein.

On either side of this vein numerous claims have been taken up and a little development work has been done. Among them are the Victoria, Cheyenne Nos. 1 and 2, Ida Bell, Ida Bell No. 2, Emma, Emma No. 2, Phœnix, and others. On some of these more or less ore has been discovered, but no large development work has yet been done. Farther west, on the Kalamazoo and Little Joe claims, a quartz vein, striking in a general northwesterly direction, has been explored by several small openings along a distance of about 500 feet. (See map, Pl. XI.) This vein is approximately parallel to that on which the Victor, Smuggler, Lee, and Buena Vista mines are situated, and belongs to

a similar system of fissuring. On these same claims other smaller veins have been developed which trend in a course diagonal to the main vein. Still farther west the Horse Shoe mine has been opened by a shaft 100 feet deep on the granitic breccia which comprises the western part of Bull Hill, while near this is the Albany tunnel, which intersects both the granite and the granitic breccia for a distance of several hundred feet.

Little May mine.—The Little May No. 1 claim is a few hundred feet southeast of the Victor mine, and is developed by a shaft about 150 feet deep with some drifting and cross-cutting. The vein is in a soft, tufaceous, and but little altered breccia, and is composed mostly of quartz, colored with more or less fluorite and containing red clay and a little manganese. The mine is not at present being worked.

Zenobia, Pharmacist, and Burns mines.—These three claims adjoin each other on Bull Hill, and the principal developments on all of them are on one vein, so that they are discussed together; though in the Zenobia mine another vein is also worked. The Zenobia claim is developed by a shaft 215 feet deep, the Pharmacist by a shaft about 400 feet deep, and the Burns by a shaft 130 feet deep, with considerable drifting in all three. The drifts of the Zenobia connect in one place with those of the Pharmacist, and the latter with those of the Burns, so there can be no doubt that the principal workings of these three mines are on one vein. This vein is commonly known in all the mines as the Pharmacist vein, because it was first discovered in the Pharmacist mine. Another vein, however, called the Zenobia vein, because first discovered in the Zenobia mine, has been considerably explored in that mine. The Pharmacist vein has been the more productive of the two. It maintains a very regular course, varying from N. 50° E. to N. 65° E., dips west of north at angles varying from 60° to 90°, and ranges from a few inches to 4 feet in thickness. The Zenobia vein is somewhat less regular in its course, varying as it does from almost due north and south to over 20° east of north, and dipping at angles of from 60° to 80°. It ranges from 1 foot to 3 feet in thickness.

In the Zenobia mine the two veins cross, and the fissure occupied by the Zenobia vein faults the fissure occupied by the Pharmacist vein with a horizontal displacement of a few feet. The amount of throw at a depth of 141 feet on the incline of the vein is 21½ feet; at a depth of 78 feet it is 12 feet, and at a depth of 33 feet it is only 8 feet. The amount of throw on the surface can not be seen on account of the covering of soil. Both veins occur in the massive rock which comprises this part of Bull Hill and occupy well-defined lines of disturbance, marked usually by one main fissure and numerous parallel cracks. Sometimes the main fissure, especially in places in the Pharmacist vein, contains large quantities of fragments of country rock broken from the walls during its formation and subsequently cemented and partly replaced by ore. The Zenobia vein sometimes, though less

ALTMAN FROM BULL HILL.

The Pikes Peak Range in the background

often, contains similar materials. Both veins also sometimes occur in a series of numerous parallel seams of ore closely assembled in a width of a few feet. Figs. 26, 27, and 28 illustrate these different modes of occurrence.

Numerous small cross fissures or cracks intersect both veins and sometimes contain a little ore, which seems to have been deposited in them at the same time as in the main fissures, though a later movement along them has often caused a crack across the vein matter of the main fissures.

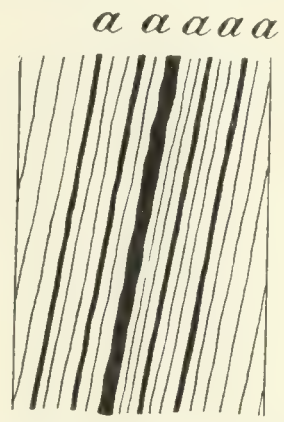


FIG. 26.—Section in Zenobia and Pharmacist mines, showing mode of occurrence of ore. *a*, veins. 1 in. = 4 ft.

The ore of the Pharmacist vein consists of the country rock more or less replaced by clear, glassy quartz, with smaller quantities of iron pyrites, iron oxides, manganese oxides, and large quantities of kaolin and iron-stained clay. When the fissure is brecciated the ore often consists of a mass of broken fragments of country rock cemented and more or less replaced by these materials. The iron and manganese are mostly in the oxidized state, though in the lower levels iron pyrites occurs, sometimes in considerable quantities, at other times in a very finely disseminated condition, giving the ore a gray appearance. Occasionally some, though very little, fluorite occurs in the ore, especially at the Pharmacist mine.

FIG. 27.—Section in the Zenobia and Pharmacist mines, showing the mode of occurrence of the ore. *a*, vein. Scale: 1 inch = 4 feet.

The Zenobia vein has been developed very much less than the Pharmacist, and most of the work done on it is in the Zenobia mine. In the Pharmacist mine what is supposed to be the same vein has been opened in one place underground and in a small pit on the surface. The ore differs considerably from that of the Pharmacist vein in containing very much less kaolin and in being composed largely of a loose, friable, vesicular quartz honeycombed by harder quartz, instead of consisting of the clear, glassy quartz of the Pharmacist vein. The vein also shows less of the brecciated structure seen in the ore of the Pharmacist vein. It consists mostly of granular quartz, stained with iron and a little manganese and containing more or less clay. The granular character of the quartz is very likely due to the removal by leaching of some of the soluble constituents of the ore. The open, porous

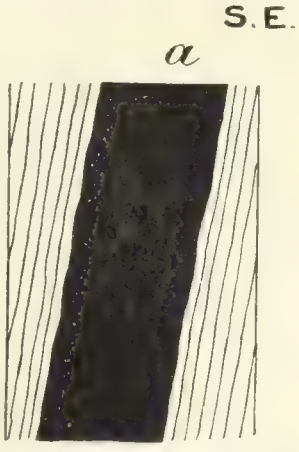


FIG. 28.—Section in Zenobia and Pharmacist mines, showing mode of occurrence of ore. *a*, vein. 1 in. = 4 ft.

character of the ore has allowed the free access of water, and the iron is thoroughly oxidized to as great depths as have yet been reached.

The gold in both veins is generally in the condition of rusty, free gold, as the ore has been thoroughly oxidized in most of the workings except the lowest parts of the Pharmacist mine. A little telluride of gold, however, has been found in some of the Pharmacist ore. As in most other parts of the district, the rich ore occurs in more or less well-defined shoots, often of considerable extent, but so far as yet determined they follow no definite system of occurrence.

To the west of these mines, higher up on Bull Hill, are a number of claims with openings on more or less well-defined veins or fissures, among which are the New Zealand, Wilson, Wallace, Jeff. Davis, and others; while to the south, lower down on the slope of the hill, are the openings on the Shirtleff and other claims, and still farther south are the Legal Tender and Longfellow mines.

Pikes Peak and Grouse mines.—The Pikes Peak and Grouse claims are south of Altman, and as they adjoin each other on the same general vein or zone of ore deposition, they are treated together. They are situated a few hundred yards south of the Zenobia mine, and in an area which is much fissured in a general direction a little west of north. The Pikes Peak claim is developed by a shaft 175 feet deep, with considerable drifting on three levels. The Grouse claim is developed by two shafts, the more southerly of which is connected in its underground workings with the Pikes Peak mine, and both of which were closed at the time the district was examined, so that the full extent of their development can not be described.

The Pikes Peak mine is on a vein in a zone of fissuring consisting of the country rock intersected by numerous parallel fissures or cracks closely assembled in a width of from 3 to 4 feet, while beyond these limits similar cracks occur, but with distance they become farther apart and less distinct. The ore consists of the country rock more or less impregnated along the cracks by iron minerals, quartz, and other materials, among which are considerable quantities of red clay derived from the wall rocks. The vein proper strikes in a general direction of N. 15° W., dips at from 85° to 90° in a west-by-south direction, and varies from an inch to a foot or more in thickness. The ore has been thoroughly oxidized to as great depths as have yet been reached, and most of the gold is yet in the form of rusty free gold, though a little telluride is said to have been found. A noticeable feature is the occasional occurrence of thin dikes of phonolite from 1 inch to 18 inches in thickness along the fissured zone. These were intruded after the formation of the fissures and before the deposition of the ore, as is proved by the facts that they sometimes intersect the fissures without being fissured themselves, and that the ore often follows and more or less impregnates them. The accompanying cut (fig. 29) will make this matter clear. This dike material is not continuous all along the fissures, but

alternately appears and disappears, though the different exposures of it may have some connection not seen in the limited underground workings. Neither are such occurrences confined to the main fissures, for at least one dike of a similar nature occurs in a subordinate fissure intersected in a crosscut a few feet east of the main vein.

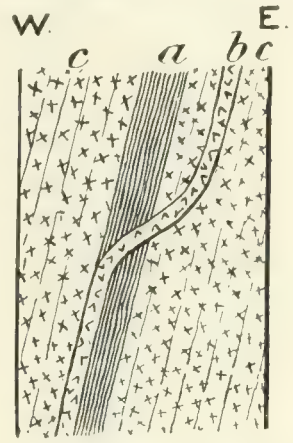


FIG. 29.—Vertical section in Pikes Peak mine, showing relation of vein and dike. *a*, vein; *b*, dike; *c*, country rock. Scale: 1 in. = 4 ft.

Another notable feature of this mine is that while at a depth the ore occurs in one vein, near the surface it forks and outcrops in three separate veins, as indicated in fig. 30. The causes of such occurrences are discussed on pages 148–149.

Considerable fissuring occurs on either side of, and approximately parallel to, the main vein at the Pikes Peak and Grouse mines. In fact, in crosscuts in the Pikes Peak mine parallel cracks sometimes containing thin layers of ore are intersected every few feet, and a considerable number of surface pits and small shafts have been sunk on thin veins of this kind, especially west and northwest of the main workings. The Mineral Rock shaft and a shaft connected with it on the southeast end of the American Eagle No. 2 claim, as well as a small opening on the southern end of the Zenobia claims, are all on veins that run in the same general direction as the Pikes Peak vein, and though they vary a little in strike from place to place, they may be looked on as belonging to one general system of fissuring. In fact, it is believed by some that this system of fissuring curves around on the Zenobia claim in a direction east of north and joins that occupied by the main Zenobia vein; but the several hundred feet of intervening ground on which no openings have been made render it impossible to prove or disprove this supposition without further exploration. In a district like the one in question, where fissures are extremely numerous and run in various directions, it is unsafe to assert that one fissure is the continuation of another unless the evidence is very strong or they have been proved by actually connected workings to be on the same fissure.

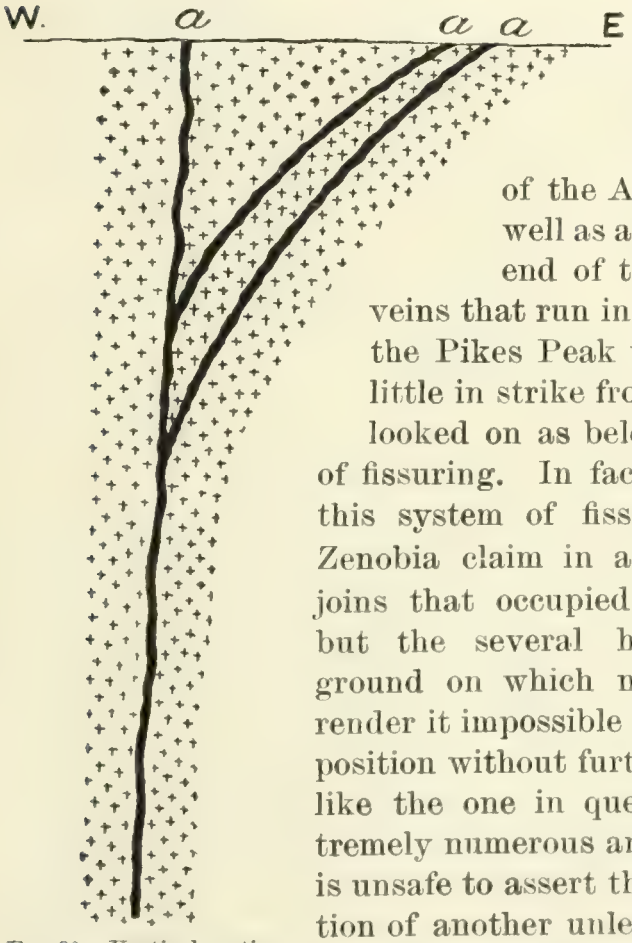


FIG. 30.—Vertical section of the Pikes Peak vein, showing the forking near the surface. *a*, veins. 1 inch = 50 feet.

To the west of the Pikes Peak and Garfield claims more or less development work has been carried on, in both

the massive eruptive rocks and the breccia on several claims, among which are the John A. Logan, Wolftone, Lottie, Favorite, and others.

Orpha May mines.—These mines are situated on the Orpha May Nos. 1 and 2 claims, which are located on Bull Hill between the Blue Bird and the Pikes Peak mines. The larger shaft is on the Orpha May No. 2 and is 106 feet deep, with drifts at two levels. The shaft on the Orpha May No. 1 is about 97 feet deep and reaches to within a few feet of the workings of the other shaft. The mines are on the same vein, in a fissured zone in massive eruptive rock, and the ore occurs in a manner very much like that already described at the Pikes Peak mine. The vein strikes N. 10° to 15° W., and dips almost vertically.

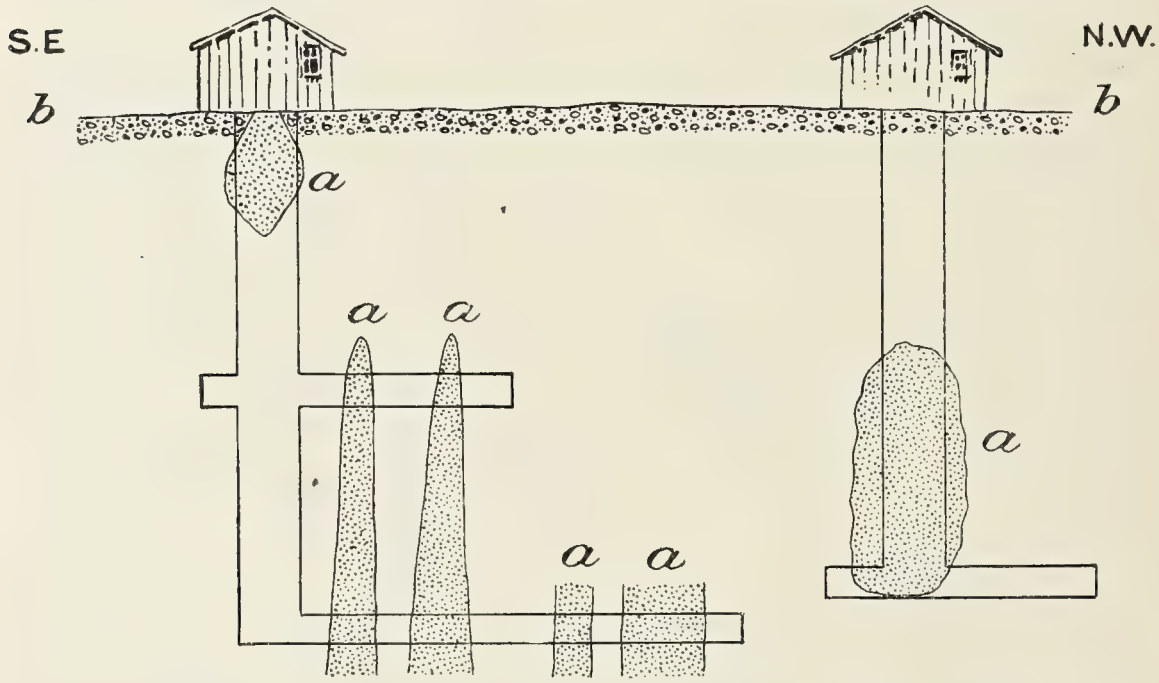


FIG. 31.—Longitudinal section in the Orpha May mines, showing the mode of occurrence of the or shoots. *a*, *a*, ore shoots; *b*, surface soil. Scale: 1 inch = 50 feet.

The best ore occurs in well-defined shoots, and outside of these there is more or less ore, but its grade is low, and the fissure is often close and contracted. The workings of the two shafts and the relation of the different shoots as at present developed are shown in fig. 31. The shoots are more likely to occur where the main fissure is intersected by cross fissures than elsewhere.

In this same vicinity more or less development work has been done on veins on the Specimen, Lafayette, and other claims.

Blue Bird mine.—The Blue Bird claim is on the southwest slope of Bull Hill and is developed by a shaft over 300 feet deep, with considerable drifting at four levels. The ore occurs in a well-developed quartz vein in the massive eruptive rock which composes this part of Bull Hill. The vein trends in a somewhat circuitous course, but has a general strike of about N. 5° E. and a dip of from 60° to 90° eastward.

At the surface it dips at from 60° to 65°, and from there the dip gradually increases, until at the bottom of the mine it is 85° to 90° and in one place even inclines a little to the west. The vein varies from a few inches to 3 feet in width, is well developed, and is composed mostly of quartz and fluorite, with iron oxides, iron pyrites, and other materials in smaller quantities, among which stibnite occasionally occurs. The quartz and fluorite are generally in the intimately mixed condition commonly known among the miners as "purple quartz" and comprise the larger part of the ore. The gold sometimes occurs as free gold and sometimes as a telluride. The fluorite is no indication of the abundance of gold, for though some of the purple quartz is rich in gold some of it is also poor. A remarkable feature of this ore is its occasional content of considerable quantities of silver. It almost always contains some silver, but sometimes the amount runs up to several hundred ounces per ton. The following assays, kindly furnished by Dr. N. W. Burdick, the owner of the mine, will give an idea of the amount of silver in some of the ores:

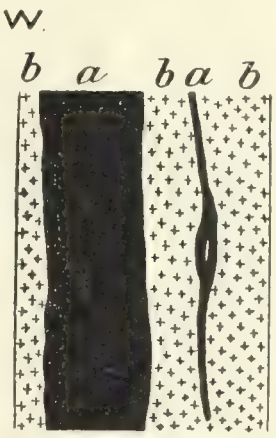


FIG. 32.—Section in the Blue Bird mine, showing mode of occurrence of the ore. *a*, veins; *b*, country rock. 1 inch = 50 feet.

FIG. 33.—Section in the Blue Bird mine, showing mode of occurrence of the ore. *a*, veins; *b*, country rock. 1 inch = 50 feet.

Analyses of ores from the Blue Bird mine.

	I.	II.	III.	IV.
Gold (ounces per ton)	20.60	0.40	28.60	70.80
Silver (ounces per ton)	70.40	1.60	251.00	204.20

The Blue Bird vein occupies a well-developed fissure, along which the wall rocks are often considerably broken and shattered, as illustrated by figs. 32 and 33.

Besides the main vein on the Blue Bird claim, subordinate veins and fissures more or less impregnated with ore also occur. To the southwest of the main shaft several surface pits have shown the existence of a phonolite dike striking in a general course a little farther east of north than the main Blue Bird vein; and at or near the contact of this dike with the country rock a marked fissuring, containing more or less ore, occurs.

A short distance farther down the mountain from the Blue Bird mine is the New York tunnel, which intersects granite and granitic breccia for a distance of several hundred feet and also discloses a vein from 6

to 8 feet in width and composed mostly of quartz and white clay much stained with manganese. The Ben Harrison and Trail claims in this same neighborhood have already been mentioned on page 187.

BATTLE MOUNTAIN.

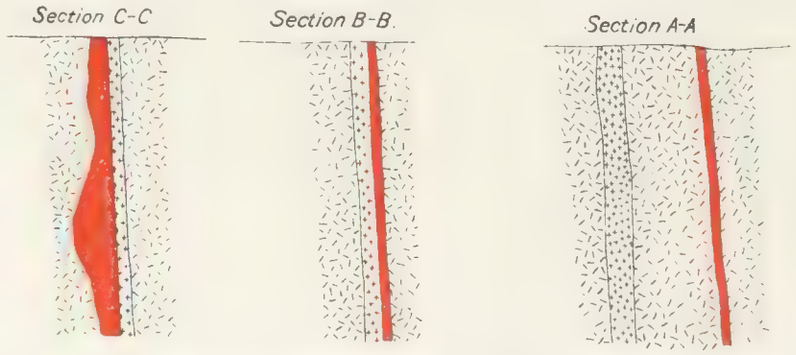
General features.—Battle Mountain is south of Bull and Raven hills, and is separated from Raven Hill by Arequa Gulch. From the early days of Cripple Creek it has been the seat of some of the most important mining operations in the district. Among the most extensively developed mines and claims are the Independence, Washington, Strong, Granite, Independence No. 4, Portland, Anna Lee, Bobtail, Black Diamond, White House, Doubtful, Dead Pine, and Eclipse, while among those on which more or less development work has been done are the Agnes, Tidal Wave, Hidden Treasure, Ocean Wave, Little Mary, Coriolanus, Sunset, and others. The town of Victor is on the south slope of Battle Mountain, near Wilson Creek.

Battle Mountain consists of an area of volcanic rocks surrounded on the east, south, and west by granite, and on the north by other volcanic materials. The mountain is composed mostly of breccia, intersected by numerous dikes which cut indiscriminately both the breccia and the neighboring granite; while in some places, especially on the eastern slope, large, irregular bodies of massive eruptive rocks occur in the breccia. The granite on the south slope of the mountain dips under the breccia, so that probably some of the mines started in breccia on this part of the mountain may pass into granite at greater depths than they have yet reached. The ore will doubtless also extend into this granite. The veins occur both in fissures or fissured zones independent of dikes and also in fissures more or less closely connected with dikes. In some cases the veins are well-defined bodies of quartz, in other cases they are impregnations and partial replacements of the country rock with mineral matter along fissures. The prominent veins are both in the breccia and in the granite immediately adjoining the breccia area.

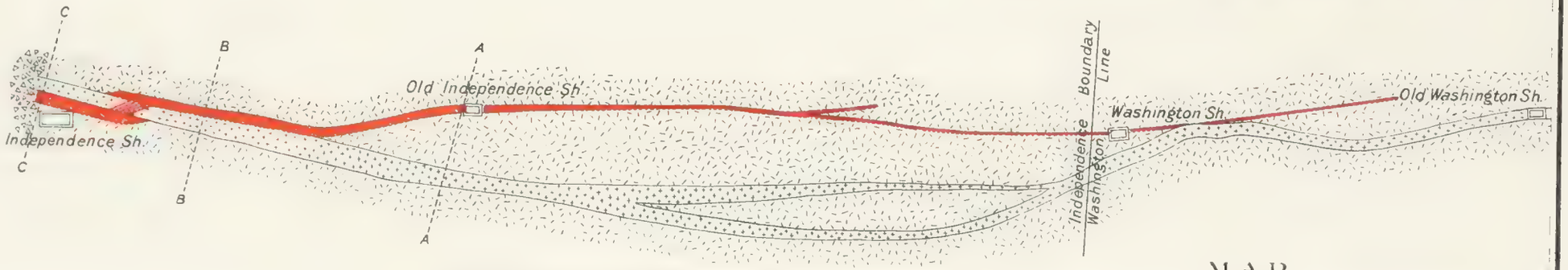
Independence and Washington mines.—The Independence and Washington mines are on the south slope of Battle Mountain, just above the town of Victor, and are for the most part on the same vein, so that they are discussed together. They were among the first mines opened in the Cripple Creek district, and the Independence has from the beginning been a large and steady producer. The latter claim is opened by two shafts, one over 200 feet deep, the other 70 feet deep, and both are connected by drifts. The Washington claim is opened by two shafts, one 60 feet deep, and another, now abandoned and partly filled with water, said to be 150 feet deep. The accompanying map (Pl. XIV) shows the position of the shafts on both claims.

The mining so far done has been mostly along one fissure or fissured zone in the granite, though the old Washington shaft, that is, the more

Plan of the 109 ft level in the Independence Mine



Vertical Sections of Independence Mine.



Surface Plan of the Independence and Washington Mines

MAP
OF THE
INDEPENDENCE AND WASHINGTON CLAIMS
SHOWING THE RELATION OF THE VEINS TO THE DIKES
BY
R. A. F. PENROSE, JR.

VEINS — DIKES — BRECCIA — GRANITE

SCALE IN FEET

0 5 10 15 30 60 90 120

southerly one, is on separate fissures. The main fissure and the one containing the ore now being worked varies in its course from a little east of north to 20° or more west of north, and has an average trend of almost due north and south. It dips from 85° to 90° to the east, and the ore varies from a few inches to over 15 feet in thickness. It follows in a general way the course of a phonolite dike which varies from 3 to 6 feet in thickness, and is sometimes close up against it, at other times several feet away, as shown in the map (Pl XIV). On the Washington claim and on the southern part of the Independence claim the vein is on the east side of the dike, but at the main Independence shaft it crosses the dike and continues thence on the west side until the granite is cut off in the northern part of the Independence workings by the breccia of the main part of Battle Mountain. The dike continues in the breccia and has been opened in a surface pit about 100 feet north of the contact; but the extension of the vein in the breccia has not yet been explored. The contact of the granite and the breccia, where it is exposed underground, runs in an easterly and westerly direction, and dips northward at angles varying from 25° to 70°, and averaging about 45°. It is sharp and well-defined, and does not show the usual shattering and brecciation of the granite seen at similar contacts elsewhere in the district. The only sign of disturbance is a faint fissuring marked by indistinct lines in both rocks parallel to the contact. This contact sometimes contains a thin film of ore, which was probably deposited at the same time as that along the main fissure.

The ore as developed in the granite occupies a well-defined fissure with numerous parallel cracks on either side, from 1 inch to 12 inches apart, and grouped together in a zone of parallel fissuring. The ore is sometimes confined to the rock which has been replaced along both sides of the one main fissure, but often it also impregnates the subordinate cracks, giving the ore a width of from 1 foot to 15 feet. The ore is due altogether to an impregnation and replacement of the granite along the fissures, and there are usually no well-defined walls, the ore on the sides simply blending into the country rock. Sometimes, however, the lateral limit of replacement happens to be marked by one of the parallel cracks already mentioned, and then there is a well-defined line between ore and rock. (See p. 145.)

Where the vein crosses the dike the character of the fissure is much changed, for instead of the ore occurring mostly along or on both sides of a principal fissure, it occurs in a great number of faint parallel cracks, among which no one is especially well-defined; but as soon as the vein reaches the granite on the other side of the dike it again assumes its normal condition.

The ore of the Independence mine consists of granite from which the mica and quartz have been partly or wholly removed, leaving a honeycombed, vesicular mass of partially kaolinized feldspar (see p. 161) in

which the cavities have been later filled partly or wholly by secondary quartz with more or less iron pyrites, a little fluorite, and other minerals in smaller quantities, among which is telluride of gold. In such a porous material surface waters have had a free channel for their percolation, and the iron pyrites is largely but not wholly oxidized down to the lower levels, while the telluride of gold has also been partly converted to free gold. It is a noticeable fact, however, that where the vein crosses the dike the gold still exists in the telluride form, even near the surface, for here the surface waters do not have such free access as in the more open granite.

The gold in the Independence mine occurs more or less continuously throughout the area opened, but in the Washington mine its occurrence is somewhat more variable. The ore in the new shaft on the north end of the latter claim can be shown by underground and surface developments to be in the same fissure as that of the Independence mine, though sometimes it extends short distances into cross fissures.

The old Washington shaft, on the southern part of the claim, is on the same dike as that at the new Washington shaft and at the Independence mine, but it is on a different fissure, for the main fissure already described diverges to the east before it reaches this shaft.

The Independence No. 4 mine is a short distance north of the Independence, and is a shaft 100 feet deep with a little drifting on a shattered zone in the breccia approximately along the contact of a dike, but not always adhering to it. The breccia contains, besides fragments of volcanic rocks, large quantities of granite fragments, some of them several feet in diameter, and the ore consists of these volcanic and granitic materials more or less impregnated with quartz, iron pyrites, iron oxides, fluorite, and other materials.

Strong mine.—The Strong claim is on the south slope of Battle Mountain, a few hundred feet west of the Independence claim, and is developed by a shaft 230 feet deep with considerable drifting at three levels. The mine is on a fissured zone in the granite running approximately along a phonolite dike in a manner very similar to that already described in the Independence and Washington mines. The fissuring and the dike have a general course of almost north and south, though they both vary locally from this direction, and they dip from 85° to 90° to the east. This fissuring consists of a series of parallel cracks, often indistinctly defined, but generally with one more prominent than the others, and the vein matter impregnates this zone for a width of from 1 inch to 12 inches or more. The dike sometimes contains ore, especially where the vein comes close to it, but the actual contact of the dike and the granite is usually very close, so that the ore is commonly a few inches away, in the granite, while sometimes it is several feet away. In one place in the mine the vein forks and one arm follows the dike while the other diverges at a low angle to the west.

The vein, so far as yet opened up, is confined entirely to the west side of the dike. The dike itself and the granite on the east side are often faintly fissured by parallel cracks, but as yet no ore has been found in any of the fissures east of the dike. A few feet to the west of the main vein, however, a parallel vein occupying a similar zone of fissuring has been found and worked to a small extent, while further exploration may yet develop other parallel veins not only on the west but also on the east side of the main vein.

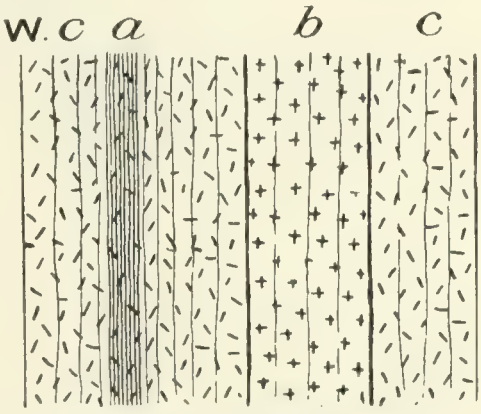


FIG. 34.—Section in the Granite mine, showing the relation of vein to dike *a*, vein; *b*, dike; *c*, granite. 1 inch = 4 feet.

The ore of the Strong mine is much like that at the Independence, except that it is less open and porous. The mica has been mostly or wholly removed, as has also part of the quartz, while secondary quartz, iron pyrites, and a little fluorite and other minerals have been introduced. The iron pyrites is often in a state of very fine subdivision, giving the quartz a gray appearance, though it has been mostly oxidized in the upper workings. The gold is mostly in the form of telluride and free gold derived from the oxidation of the telluride. The ore occurs in shoots of considerable size and of irregular shape.

Granite mine.—The Granite claim is on the south slope of Battle Mountain, a short distance northwest of the Strong mine. It is developed by a shaft 153 feet deep, with drifting on three levels. The nature and occurrence of the ore are very much the same as already described at the Strong mine, and therefore need not be discussed in detail here. The vein follows in a general way a phonolite dike, though it often recedes from it for several feet and then returns. It strikes in a general course of from a few degrees east of north to about northwest and dips almost vertically. The gold occurs in the form of telluride of gold and of free gold derived from the oxidation of the telluride. The ore is confined almost entirely to the granite, but in a few places, where the fissure is partly in the dike and partly in the granite, and also where it crosses the dike, the latter is sometimes impregnated with more or less ore, as shown in figs. 34, 35, and 36. Most of the mining has been done on the vein where it is on the east side of the dike, but in the northern part of the workings it passes through the dike, as shown in fig. 36, in a manner somewhat similar to that already described at the Independence mine.

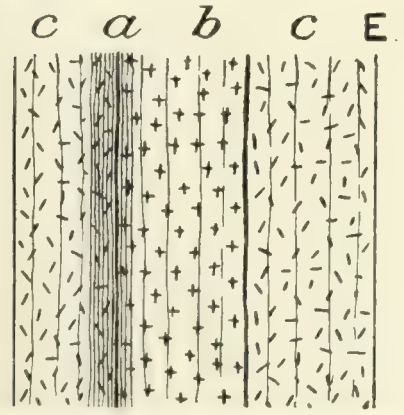


FIG. 35.—Section in the Granite mine, showing the relation of vein to dike. *a*, vein; *b*, dike; *c*, granite. 1 in. = 4 feet.

Above the Granite mine, on Battle Mountain, more or less development work has been done on several other claims, among which are the Dead Pine, the Coriolanus, Little Mary, and others.

Portland group of mines.—This group of mines includes the Portland mine proper, the Doubtful, White House, Anna Lee, Bob Tail, and others, and it is one of the most productive properties in the district. Owing, however, to litigation now pending, the writer, though permitted to examine thoroughly all the workings, has not been allowed to publish extensive details, and therefore the descriptions given here are necessarily somewhat short.

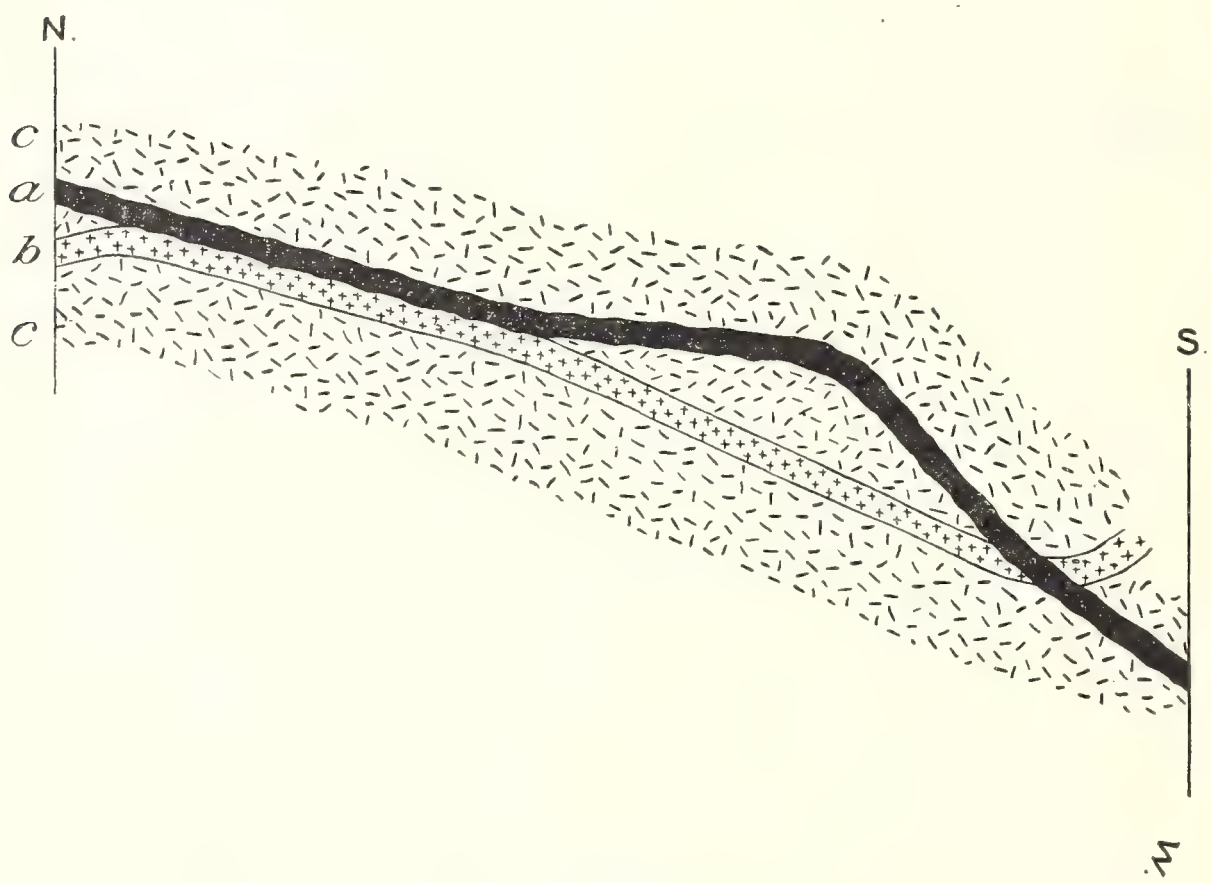


FIG. 36.—Horizontal plan in the first level of the Granite mine, showing the relation of the vein to the dike. *a*, vein; *b*, dike; *c*, granite. Scale: 1 inch = 25 feet.

The Portland claim is a short distance up the slope of Battle Mountain from the Independence and Strong mines. The main workings are in the Portland shaft, which is 225 feet deep, with considerable drifting, while smaller openings near by have been less developed. The main openings are on an area of breccia which is intersected by numerous parallel or approximately parallel fissures, generally several inches or several feet apart, but sometimes closely assembled in zones of fissuring in which they are often only a fraction of an inch apart. It is in such zones of close fissuring that the veins usually occur, though thin layers of ore are sometimes found in the isolated cracks. A dike passes longitudinally along this fissured area, and is itself fissured in the same

way as the inclosing rock. The dike and the fissures follow a general west and northwest course, and dip to the southwest.

The principal Portland workings are on three main veins, with minor workings on subordinate seams. Two of the main veins are in the breccia and one is in the dike between the other two. The vein to the east of the dike is known as the "foot-wall vein" and the vein to the west is known as the "hanging-wall vein." What is known as the "sylvanite vein" is a thin seam in the breccia, rich in telluride ore. All the veins consist of the rock more or less replaced by quartz, iron pyrites and iron oxides, a little fluorite, and other minerals in smaller quantities. The gold is in the form of telluride and of free gold.

The Doubtful and White House shafts are near the Portland and are on veins in the same general fissured area. The Bob Tail mine is a shaft 105 feet deep a short distance west of the Portland shaft, and is on a quartz vein in a fissured zone in the breccia, striking N. 50° to 60° W.

The Black Diamond claim is near the Portland and is developed by three shafts, the principal one, 280 feet deep, being partly on a dike. Among the other claims in this part of Battle Mountain may be mentioned the Tidal Wave, which is west of the Portland and has been developed by a small shaft with a little drifting on a quartz vein with iron pyrites and other material, trending in a general direction a few degrees north of west.

The Anna Lee mine is a few hundred yards northwest of the Portland mine, and consists of a shaft 400 feet deep, with drifting at seven levels. The workings are on a chimney-shaped body of ore of a general cylindrical form, from 12 to 15 feet or more in diameter, dipping steeply and often almost vertically, and extending from the surface to the bottom of the mine. This ore body occurs in the course of a dike varying from 2 to 4 or 5 feet in thickness, though it also includes some of the country rock bordering the dike on either side, as shown in fig. 37. The dike strikes in a general direction about north-northwest, and dips almost vertically, with a little inclination to the west-southwest. The country rock is the breccia which comprises most of this part of Battle Mountain, and both it and the dike are fissured by a series of parallel cracks from a few inches to a foot or more apart and running in the same general direction as the dike.

The ore body, or ore chimney, as it really is, dips with the dike and has, especially in its lower parts, a slight inclination along the dike to the southwestward, as shown in the accompanying fig. 37. It consists of a part of the dike and the breccia extensively kaolinized and more or less impregnated with quartz, iron pyrites, iron oxides, manganese oxides, and other materials. Sometimes the kaolin simply fills the cracks of the rock, sometimes it forms the cement of a few unaltered parts, and sometimes the whole rock has been more or less completely kaolinized. The altered parts of the dike and breccia are not sharply separated from the unaltered parts, but gradually blend into them. Often the

blending is accomplished in a distance of a few inches, but in some places the transition requires a distance of several feet.

The ore body seems to represent the neck of a hot spring or fumarole such as were probably abundant in the district after the subsidence of volcanic activity. The ascending hot waters kaolinized the

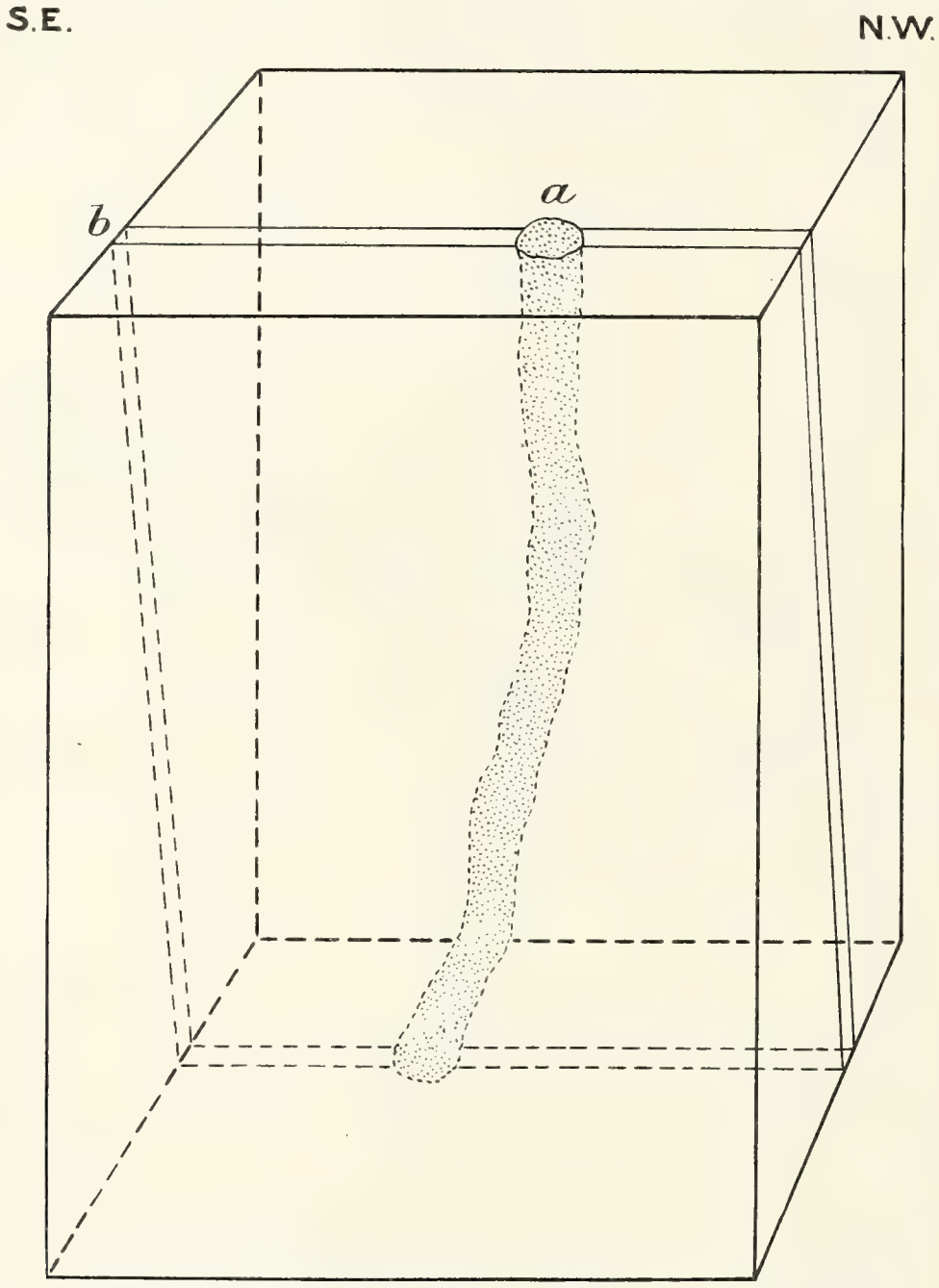


FIG. 37.—Section in the Anna Lee mine, showing the relation of the ore shoot to the dike. *a*, ore shoot; *b*, dike. Scale: 1 inch = 100 feet.

feldspathic constituents of the rock and deposited the other minerals mentioned. (See p. 160.) A similar action was doubtless the cause of most of the ore deposits of the district, the only difference being that here the waters rose along one narrow neck or chimney and formed a columnar body of ore, while in most other places they rose for greater or less distances along fissures and formed more or less

continuous veins or ore shoots. In the present case the ore body is probably connected with one or more of the fissures common in this neighborhood, and its occurrence as a chimney-shaped body, instead of along a fissure, is probably due to the fact that an unusually easy passage for the ascending waters existed along the line of the present ore body, while the rest of the fissure may have been more or less tightly closed.[1]

The Hidden Treasure claim is north of the Anna Lee shaft and is opened by a few small pits and surface cuts in the breccia and dikes.

Eclipse mine.—The Eclipse claim is on the northwest side of Battle Mountain, in Arequa Gulch, and consists of a tunnel penetrating the mountain for about 160 feet. From this tunnel drifts are run on two veins which cross it almost at right angles, while the intermediate rock is much fissured with parallel cracks often containing thin films of ore. In fact, in some places the rock is minutely shattered. The country rock is the common breccia of Battle Mountain, containing some massive rocks. The ore consists partly of the mixture of fluorite and quartz called by the miners "purple quartz," though in many places the fluorite has been removed by leaching and has left the ore in the form of a loose, brown, friable quartz commonly called "sand quartz." In the larger of the two veins more or less iron pyrites and often considerable white kaolin occur. The gold so far observed is in the free state, but is rusty and is in the form of the crystals of telluride of gold, from which it was doubtless derived by oxidation.

About 500 feet south of the Eclipse mine is the Sunset tunnel, which runs into Battle Mountain for about 300 feet. It is in the common breccia of Battle Mountain, except in a crosscut to the south, which intersects the granitic breccia and the solid granite. The tunnel intersects a fissure containing white kaolin and a little quartz, and supposed to be the continuation of the main vein in the Eclipse mine. Another vein, known as the Sunset vein, is also intersected, and consists of a well-defined body of quartz, trending in a general N. 30° E. direction and varying from 1 to 4 feet in thickness.

SQUAW MOUNTAIN.

General features.—Squaw Mountain adjoins Battle Mountain on the west and forms a part of the divide between Arequa Gulch and Wilson Creek. It consists largely of granite cut by numerous dikes, and in the sag which separates it from Battle Mountain the granite ends and the volcanic breccia begins, the adjoining part of the breccia containing large quantities of granite fragments. Squaw Mountain has been subjected to the same fissuring as the other parts of the district, and a number of claims have been taken up on more or less well-defined veins in

[1] The sides of the various underground workings in this mine are, except in a few places, inaccessible, and it was only in the bottom of the mine that detailed observations could be made at the time it was examined.

these fissures. No extensive mining, however, has yet been done, though operations are being carried on at various points, especially on the April Fool and Santa Rita claims. Among the other claims on the mountain are the War Eagle, May B., Flower of the West, and others.

LAWRENCE TOWN-SITE.

General features.—The Lawrence town-site is a tract of land originally laid out for the town of Lawrence. It covers a considerable area lying south of Battle and Squaw mountains in the valley of Wilson Creek, and has been the field of more or less prospecting. It is worked on the lease system, by which certain areas are let to individuals for mining purposes. Among some of the openings in this area are the Elkton No. 3, May Belle, Smith shaft, Dillon shaft, and others. The whole of this tract is composed of granite cut by numerous dikes, and it represents a part of the granite area south of the vent which produced the volcanic materials of the central part of the Cripple Creek district. The same systems of fissures which intersect the volcanic area extend southward into this granite region, and many of the fissures seem to be the direct southerly continuation of fissures or fissured zones to the north. Many of these fissures are impregnated with quartz, iron minerals, fluorite, sometimes a very little galena, and more or less gold, thus forming the ore of this locality.

Still farther south considerable prospecting has been done in the granite and eruptive rocks of Grouse, Straub, and Little Pisgah mountains, but developments have as yet been limited. The same may be said of Big Bull Hill, to the southeast of the main Cripple Creek district.

GILLETTE.

General features.—The town of Gillette is on Beaver Creek, northeast of Tenderfoot Hill, and in the hills to the west of the town numerous claims have been taken up and more or less mining has been done. Among the more prominent claims are the Lincoln, King of Diamonds, Mary McGee, Lizzie Eleanor, Eveline, Belle Plaine, and others. The region is mostly a granite area lying northeast of the main area of eruptive rocks and intersected by numerous dikes. It has been subjected to the same general fissuring as the rest of the Cripple Creek district, and in many of the fissures ore has been deposited. Sometimes the ore is in granite at the contact with dikes, as on the Mary McGee and other claims, while in other places it is in fissures in the granite some distance from dikes, as in the Lincoln and King of Diamonds mines. The Lincoln mine is a shaft 50 feet deep, with a little drifting on two intersecting fissures, while the King of Diamonds is a shaft 80 feet deep, on a fissure striking in a direction a little east of north.

SPRING CREEK.

General features.—Spring Creek rises north of Carbonate and Tenderfoot hills, and flows westerly into Four Mile Creek, also known as Oil Creek. It is north of the region of most of the mines, but a number of claims have been taken up in the neighborhood of its upper waters, and a limited amount of mining has been done. Among them are the Maggie Trimble, Galena, No. 17, Columbus, Idaho, California, Fearless, Alice S., Small Hopes, and others. The region where most of the claims have been taken up consists largely of granite, cut by dikes and intersected by fissuring similar to that which has been described as occurring in other parts of the district. Some of these fissures carry ore, and a limited amount of galena containing both gold and silver has been shipped from small veins in the Galena and other mines. On the Maggie Trimble claim considerable quantities of loose fragments of carbonate of lead, as well as galena partly converted to carbonate, containing probably some sulphate of lead and much stained by iron, have been found in the soil, and a shaft has been sunk in search of the ore in place, but as yet this has not been found. The shaft was closed and partly filled with water at the time the claim was examined, so that it could not be inspected.

A GEOLOGICAL RECONNAISSANCE ACROSS IDAHO.

BY

GEORGE H. ELDRIDGE.

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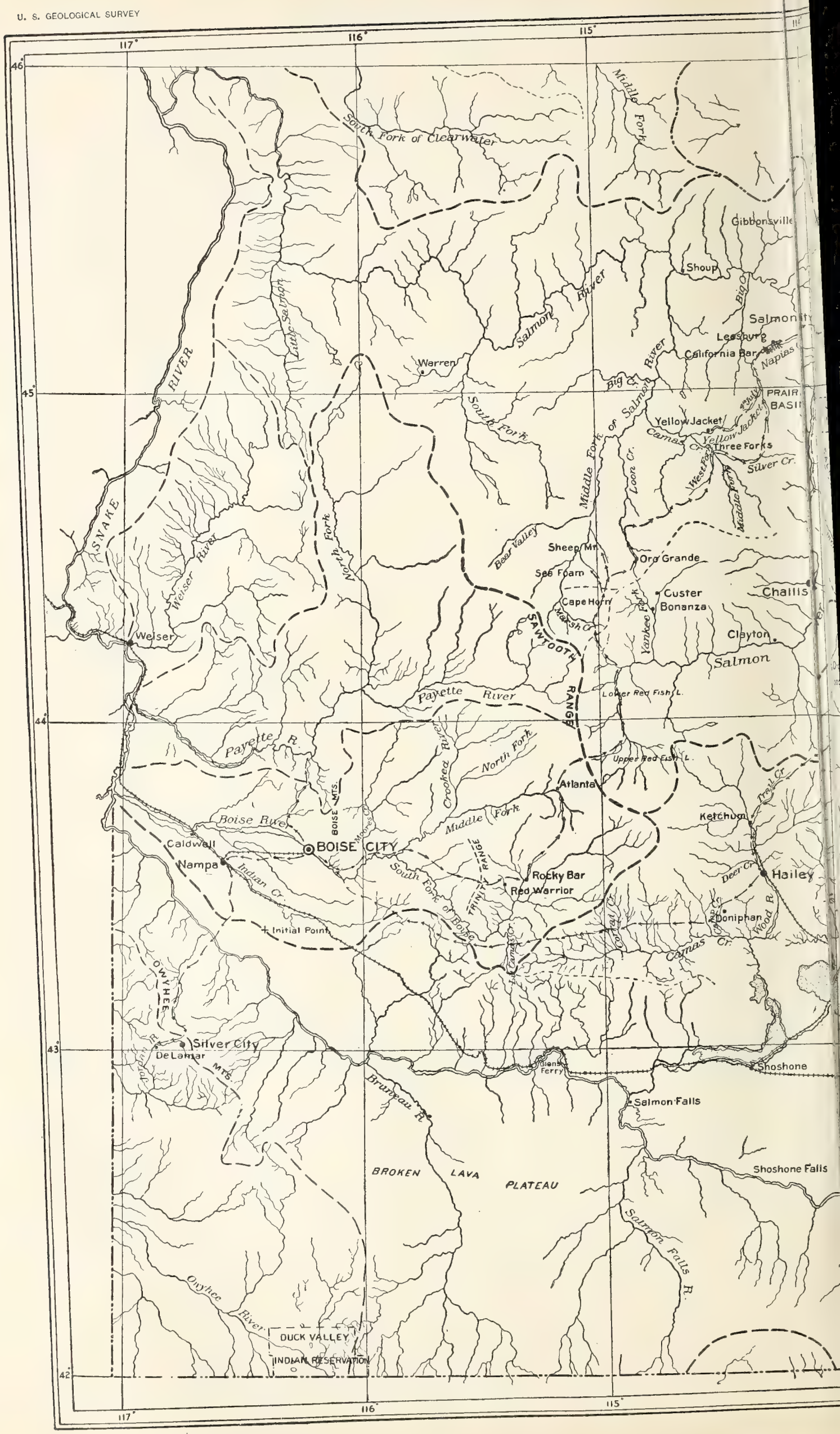
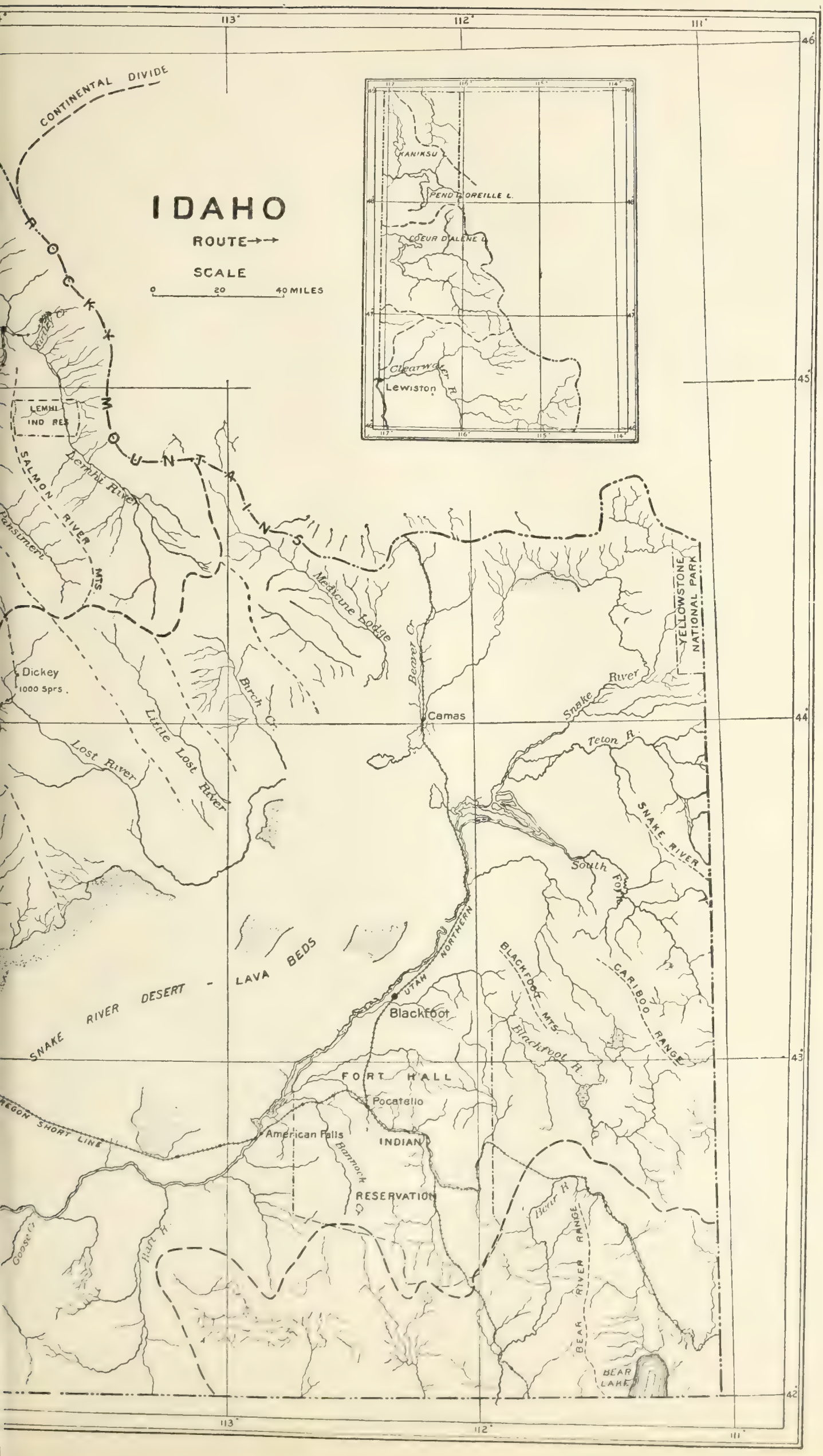


GENERAL MAP OF


IDAHO
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SALMON RIVER MTS
Lemhi River
Pansmer
Dickey
1000 Sprs.
Lost River
Little Lost River
Birch Cr.
Medicine Lodge
Beaver Cr.
Camas
Snake River
Teton R.
YELLOWSTONE NATIONAL PARK
SNAKE RIVER
South Fork
UTAH NORTHERN
Blackfoot
BLACKFOOT MTS.
Blackfoot R.
CARIBOO RANGE
SNAKE RIVER DESERT - LAVA BEDS
FORT HALL
Pocatello
INDIAN
RESERVATION
American Falls
Bannock
OREGON SHORT LINE
Goose Cr.
Raft R.
Bear R.
BEAR RIVER RANGE
BEAR LAKE
46
45
44
43
42
113°
112°
111°

ATE OF IDAHO.

A GEOLOGICAL RECONNAISSANCE ACROSS IDAHO.

By George H. Eldridge.

PREFATORY.

The following pages contain an account of a reconnaissance across Idaho on a northeast line through Boise and Salmon City. The work was authorized as a preliminary to the future geologic study of the State. In its prosecution the available maps have been the atlas sheets of the Survey, between the meridians of 114° and 117° west and the parallels of 43° and 44° 30′ north; the maps of the United States General Land Office; and a rough sketch-map of Lemhi County.[1] The general map of the State accompanying this report is a compilation from the above sources.

The fossil plant remains referred to in the text have been identified by Mr. Knowlton; the mollusks, by Messrs. Walcott and Stanton; the eruptives, by Mr. Cross; and the chemical analyses have been made in the laboratory of the Survey.

TOPOGRAPHY.

The broad topographic features of Idaho are the drainage systems of the Snake and Columbia rivers, with a vast arid plain along the former stream; a labyrinthine mass of rugged mountains northward from the plain; and a succession of desert ranges on the divide between the Snake River and the Great Basin, along the southern border of the State.

DRAINAGE SYSTEM OF THE SNAKE RIVER.

The Snake Plains, which extend completely across the southern end of Idaho, constitute one of the prominent features of the West. The floor is rolling, consisting of sand and lava underlain by Tertiary sediments several hundred feet thick. These have been cut by the river to a depth of 400 to 1,000 feet, the stream being confined between canyon walls, or lying in a valley with bottom-lands on either side. Following are a few of the determined altitudes of the plains.[2]

[1] Prepared by Mr. Birdseye, Salmon City, Idaho.

[2] Chiefly from Gannett's Dictionary of Altitudes, Bull. U. S. Geol. Survey No. 76, 1891.

Altitudes of localities on the Snake Plains.

	Feet.		Feet.
East end of Snake Plains, about	5,000	Shoshone	3,975
Camas	4,822	Bliss	3,269
Market Lake	4,781	Glenns Ferry	2,556
Eagle Rock	4,714	Boise	2,768
Blackfoot	4,505	Nampa	2,489
Pocatello	4,468	Caldwell	2,374
American Falls	4,343	Weiser	2,125
Minidoka	4,287		

These figures show a gentle gradient of approximately 3,000 feet in 400 miles, or an average of 7½ feet to the mile, a little heavier at the eastern end, a little lighter at the western.

Additional elevations along Snake River are: Lewiston, about 1,100 feet; Pasco Junction, Wash., 386 feet; Snake River (mouth), 328 feet. These indicate the maintenance, for the balance of the river's course, from Weiser to the junction with the Columbia, of a gradient of approximately 7 feet.

The drainage of Idaho, with the exception of the southeast corner and a narrow strip of 130 miles at the north, is entirely through the Snake River. The copious waters of this stream are derived from the Continental Divide in the vicinity of the Yellowstone Park, from the great mass of mountains north, and from the divide between it and the Salt Lake and Humboldt regions to the south, just beyond the border of the State. The river forms a third of the western boundary of the State, receiving along this portion the Owyhee, Boise, Payette, Weiser, Salmon, and Clearwater rivers, all draining large areas of country. Of these, the Clearwater rises in the Bitter Root Mountains; the Salmon drains an extensive interior area between the Continental Divide and a parallel range, the Sawtooth, in the middle of the State; the Boise and Payette drain from the latter range west; the Weiser occupies a longitudinal valley parallel with the Snake, from which it is separated by a narrow, rugged range, the continuation of the Seven Devils Mountains; and the Owyhee drains the southwestern corner of the State. The Palouse River, also a tributary of the Snake, drains a small scope of territory just north of the Clearwater, within the western edge of the State.

DRAINAGE SYSTEM OF THE COLUMBIA RIVER.

From the divide north of the Palouse and the Clearwater the drainage is to the Columbia, through the Spokane River, Clarks Fork, and the Kootenai, the first of these, with its tributaries, heading within the State, in the Bitter Root Mountains, the others crossing it from Montana. Of the larger lakes in this system, Cœur d'Alene has an altitude above sea-level of 2,150 feet; Pend d'Oreille, 2,080 feet.

The distribution and relative areas of the several drainage basins are shown on the general map.

MOUNTAINS.

The portion of Idaho lying north of the Snake Plains is an intricate region of lofty mountains and deep canyons. The altitude of the mountains varies between 6,000 and 12,000 feet, while 3,000 to 4,000 feet is a common depth for the canyons. The mountains lie either "en masse"—nearly devoid of topographic system—or in ranges. The development "en masse" is due to early geologic accidents—fracturing, faulting, and folding—and subsequent modification by erosion, the region being one of nearly structureless granite of almost homogeneous texture. The range form, on the contrary, is the effect of erosion either upon pronounced folds in sedimentary beds and foliated granites or upon a complex in which there existed a difference in the texture and hardness of the rocks, decay and disintegration taking place more rapidly in one than in another.

The range of first importance in the topography of Idaho is the Continental Divide. This consists of folded metamorphosed beds—quartzites and schists—the structural and topographic axes coinciding. Second in importance are the ranges dividing the chief drainage basins. Among these are the Sawtooth, in the center of the State, nearly parallel with the Continental Divide; two north and south ranges on the western side of the State—the Seven Devils between the Snake and Weiser rivers, and a shorter ridge between the latter stream and the North Fork of the Payette; a transverse ridge of irregular trend extending from the southern end of the main Sawtooth Range to the Continental Divide, and separating the Salmon waters from those of the Snake to the south; a ridge north of and having the same direction as the last, springing from the Sawtooth in the vicinity of Cape Horn, and constituting the watershed of the main and middle forks of the Salmon; and a range from the Sawtooth west, dividing the Boise and Payette drainage. Of these secondary ranges, the two in the western part of the State are unknown to the writer; the others were crossed once or twice. The Sawtooth and the northern of the transverse ridges are composed chiefly of granite, with local eruptives, while the southern transverse ridge consists in part of granite and in part of more or less metamorphosed sedimentary beds cut by eruptives and folded. Subordinate still to the foregoing are the ranges separating the major water courses within the several drainage basins. Particularly noticeable among these are the Salmon and Lost River ranges and others just to their west, in eastern Idaho, largely composed of folded metamorphic rocks; the north and south ranges between the several forks of the Salmon River, springing from the northern of the transverse ridges and consisting chiefly of structureless granite, except at the east, where quartzites prevail; the ranges between the Boise and Payette basins, also of granite; and finally the Owyhee Range in southwestern Idaho, consisting of granite and eruptives.

The mountains of purest range type occur chiefly in the eastern part of the State, in proximity to the Continental Divide, in a region of uplifted sedimentaries, altered or unaltered quartzites, schists, and limestones. West of this area, in the region of granite, the "en masse" form prevails; but the range type is still present in the Owyhee, Boise, Trinity, Sawtooth, and transverse ranges, where the granite is strongly foliated or the rocks are of different texture and hardness and erosion has removed one class faster than another.

CANYONS AND INTERMONTANE VALLEYS.

Throughout the mountain region are many quite impassable canyons, and others hardly less so. The early prospectors, prior to last year (1894), had made a few passable with trails, and recently the Salmon above Salmon City has been opened by a portion of the State wagon-road. The walls of the canyons are precipitous, sheer drops of 1,000 feet being not infrequent, while the confining slopes rise from 2,000 to 3,000 feet higher. The bottoms are filled with débris, the streams being swift and wild. Among the most rugged of the canyons are: the canyon of the South Fork of the Boise; several along the Salmon; that of the Middle Fork of the Salmon, with its tributary, Loon Creek; and those of the numerous branches of the Clearwater.

Within the mountains, also, are occasionally to be found open valleys from 10 to 20 miles in length by 2 to 7 or 8 in width. They have become the repositories of the products of modern erosion, or of materials derived from the inclosing mountains and laid down in Tertiary times or their early canyons have been filled to depths of several hundred feet with lava-flows, to be recut by later streams to their present levels.

Prominent among these valleys are the following: Along the portion of the Salmon traversed, one at the head of the main fork, east of the Sawtooth Range. There is here a stretch of nearly 40 miles north and south by 6 or 8 east and west occupied by material, chiefly crystalline and eruptive, derived from the surrounding mountains. Long and gentle talus slopes border the valley, while its center is a broad flat, cut to a depth of 5 to 30 feet by the river channel. The valley was probably once the site of a glacial lake, heavy beds of morainal matter being still visible along the base of the Sawtooth.

At Challis is another opening. This in itself is 10 or 15 miles in diameter, but tributary valleys to the east and west carry the general topographic depression some 10 to 15 miles farther back. The Salmon enters the valley 7 miles southeast of Challis through a sharp canyon in crystalline and eruptive rocks, and after a northerly course of about 15 miles, along which are rich bottom and bench lands, again enters the mountains in a canyon continuous—with the exception of a small opening in the vicinity of the Pahsimeri—to within 6 or 7 miles of Salmon City. The valley of Antelope Creek, the tributary from the east, is broad and level, the stream small. The valleys to the west are more

rolling, but the creeks, again, carry little water. There is a deep deposit of Quaternary gravel in the Challis Valley, but the evidence of glacial action, along the route traversed at least, is not nearly so pronounced as in the upper valley of the Salmon east of the Sawtooth Range.

The Pahsimeri Valley appears open for fully 15 miles from its mouth. It is 6 or 7 miles broad, with a narrow strip of bottom land along the center, the remainder being bench land underlain with Quaternary débris resting upon crystallines and eruptives.

A third and still broader intermontane valley of the Salmon occurs about Salmon City. This is an illustration of the mountain-locked valleys that have become repositories of materials in Tertiary times. The depth of the pre-Tertiary valley is unknown, but the sediments indicate it to have been several hundred feet greater than at present. The extent of the valley is about 20 miles along the Salmon, in a north and south direction, by 10 miles in an east and west direction. To the southeast it is continued, in the Lemhi Valley, fully 30 miles, maintaining here a width of 5 to 8 miles. A long spur of the Salmon River Range lies in the forks of the valleys. Both the Salmon and Lemhi valleys present gentle slopes from side to center, locally rendered somewhat uneven by the folds into which the Tertiary beds have been thrown. Along the present stream channels, particularly the Salmon, the Tertiary strata frequently form precipitous bluffs 50 to 80 feet high. The first-bottom lands are from a half mile to 1 or 2 miles wide, but there is generally a long, evenly sloping bench on one side or the other which is susceptible of cultivation wherever water is available. The configuration of the valley has perhaps changed slightly from time to time, not only by reason of erosion, but also through the agency of dynamic movements, indicated by flexures in the Tertiary strata.

Of the other intermontane valleys, that of Lost River was traversed only along the two branches forming its head. The northern of these has its source in the Thousand Springs, near Dickey. The valley is here 3 or 4 miles broad and very level; just below it opens to a still greater width and becomes continuous with the main valley below the forks. The west or main fork has a narrow bottom, rarely over a half mile wide, confined between rugged hills from 600 to 2,000 feet high.

The valley of Wood River from a point about 15 miles above Ketchum to its exit from the mountains maintains a width of bottom of between one-half and 1½ miles. The floor is level, and is underlain with a Quaternary wash of varied material. The tributary valleys are usually sharp mountain gorges, their bottoms rarely over one-quarter mile wide.

From Hailey to Boise the route of reconnaissance lay along the southern border of the mountain mass of Idaho; for the eastern half of the distance, in the broad, prairie-like valley of Camas Creek; for the western half—from High Prairie at the head of Camas Creek to the Boise Valley—within the foothills of the mountains. The valley of Camas Creek is from 10 to 15 miles wide, extending directly from

the base of the mountains on its north to the low range of hills—partly sedimentary, partly crystalline or eruptive—which divides it from the Snake Plains to the south. The channel of Camas Creek is deep cut, but the lateral streams are rarely depressed more than 10 or 15 feet. Were the water supply sufficient the valley would present some of the most favorable agricultural conditions observed during the reconnaissance.

From the Camas Valley westward for a distance of 25 or 30 miles is a region of high, irregularly eroded hills, extending from the mountains prairieward 10 to 15 miles. The drainage of this area is partly into the Boise, partly direct to the Snake River. The divide between the two waters threads its way with irregular trend through the region, passing finally into the great lava flat which constitutes a part of the Snake Plains at their western end. From this divide, at the head of Indian Creek, a high range passes northwest and walls the Boise intermontane drainage basin from the general valley without. The Boise River debouches from a rugged defile in the range at a point about 12 miles southeast of Boise City. In the vicinity of Little Camas Prairie, however, the early topographic rim, confining on the south the intermontane drainage of the South Fork of the Boise, has been deeply degraded, and but for the cutting of the stream—its recutting, even, through the comparatively recent lavas—at a more rapid rate than the denudation of the rim, the waters of the South Fork would have found an exit at this point direct to the Snake. In the hill area just described the valley of greatest extent is that of the Little Camas, 7 or 8 miles long and from 1 to 5 miles wide. Meadow lands occupy its upper, narrower portion, while below it assumes a prairie aspect and is underlain by a broad flow of lava. A ridge 2,000 feet high extends across the southern end of the valley, and continues eastward for several miles as the southern border, also, of the Big Camas Valley. The entire foothill region between the head of Big Camas Creek and the main Boise Valley west of the mountains is one of granite, lava, and other eruptives in dike form, and the effect of such varied rock assemblage has been a most irregular development of topographic features. The lava generally occurs as a thin sheet or a succession of thin sheets upon the granite, and wherever it is present the country becomes rough and difficult to travel.

North of the region just described and within the rim of the Boise drainage basin is a flat, 8 to 10 miles in diameter, known as Smiths Prairie. The floor is wholly of lava, which extends, also, for some distance into the tributary valleys. The surface is locally smooth, rugose, or gently undulating, and in only one or two instances is it relieved by low hills. The general altitude of the surface is about 4,800 feet, a little lower than the small lava prairie a few miles to the southeast at the mouth of Little Camas Creek. Along the southern edge of the prairie the South Fork of the Boise has cut a gorge over 1,000 feet deep, in the precipitous walls of which appear two seemingly distinct lava-flows, one occupying the upper 500 to 700 feet of the gorge, the other 200 to 300 feet at the bottom. The relative ages of these flows were not

determined, but either might be the older. The flows may be traced at intervals the entire length of the South Fork, and also along the main stream below, to its debouchment from the mountains. At the mouth of Moores Creek they are joined by others which extend nearly to Idaho City. Usually the lava forms narrow ribbons adhering to the sides of the canyons. These appear to drop in altitude as the canyon is descended, indicating an ancient lava river down an earlier-eroded gorge, with occasional lava lakes in the openings.

Twenty-eight miles north of Boise, at Horseshoe Bend, on the Payette, is a small mountain-locked valley carrying deposits of Tertiary age. The length of the valley is 10 to 12 miles, the width 4 or 5 miles, the trend northeast. Along the western edge the Payette flows for a distance of 5 or 6 miles, entering and leaving by a sharp, rugged canyon in the granite of the Boise Range. The valley is apparently one of erosion. Its configuration is somewhat irregular, both upon original outlines and from the later encroachment of the heavy talus slopes along the base of the mountains. Moreover, the underlying Tertiary beds here and there project through the Quaternary in buttes or ridges. Gentle folding has taken place here, as in the valley at Salmon City.

One of the most peculiar valleys encountered, of which the topographic origin was not determined, is that locally known as "Prairie Basin," about 45 miles southwest of Leesburg. This is a high intermontane depression, apparently of considerable depth originally, but since filled by heavy deposits of glacial drift, which in still later times has been partially removed through the channels of Big Creek and its tributaries. The valley surface is now in long, rounded ridges and hillocks. Owing to its altitude, to the extent of opening, and to the heavy growth of grass covering its every acre, the "basin" is easily recognized from distant peaks.

GLACIAL ACTION.

Evidences of early glaciers were observed at many points along the route of reconnaissance, and it is probable that their existence was quite general throughout the mountain region of Idaho. Conspicuous localities in the southern half of the State are the Trinity and Sawtooth ranges. In the upper portions of many of the valleys heading in the former are glacial bowlders, grooved rock surfaces, roches moutonnées, and lateral and terminal moraines. North of the Trinity Range, and also east of the Sawtooth, are numerous glacial lakes, 1 to 2 miles in diameter, their waters held back by terminal moraines. East of the Sawtooth the mass of débris from the earlier glaciers is enormous, extending 50 or 60 miles along its front and forming a belt from 5 to 8 miles broad. This is cut by the streams of the present day, and now forms a rough, often heavily timbered slope most difficult to traverse. Other observed localities are the ranges west of Salmon City, particularly about the head of Panther Creek and the several tributaries of the Yellow Jacket, a branch of Camas Creek. Prairie Basin has already

been noted as the possible site of an ancient glacial lake, the heavy deposit of bowlders having been derived from the surrounding mountains. Indeed, nearly all of the valleys traversed in the reconnaissance show, at their heads, more or less evidence of former glaciers. Even now ice action is rife at the higher altitudes, where the snows are exceedingly deep and their disappearance is rarely complete from one season to another.

THE FORMATIONS.

The rocks occurring in the southern half of Idaho embrace granites, gneisses, syenites, schists, quartzites, limestones, calcareous and noncalcareous shales, sandstones, clays, and eruptives in great variety. The granites and syenites, in part at least, are probably of the Archean age; the schists, Algonkian. The quartzites are distributed from Algonkian to Carboniferous, while the limestones may include both Silurian and Carboniferous. The age of the great calcareous shale series of the Wood River and neighboring districts is undetermined, but the evidence points to the Carboniferous. It is undoubtedly Paleozoic. The sandstones and clays encountered are all of Tertiary age, Eocene (?) and Neocene. Post-Pliocene gravels are abundant. The eruptives are possibly of all ages, from Archean to Recent. The assignment of the several series of rocks, except the sub-Carboniferous and Tertiaries, is provisional, being without fossil evidence; lithology and stratigraphy alone form the basis of reference. Fossils might be found at several horizons, but the exigencies of the trip did not permit careful search.

GRANITES AND METAMORPHIC ROCKS.

ARCHEAN.

To this group are provisionally assigned the granite and gneiss, but there are instances where, by reason of included bands of calcareo-micaceous or quartzitic slates, this reference to the Archean instead of the Algonkian is questionable. Again, it is probable that, in part at least, the granite is of igneous origin.

The granite is of wide occurrence, and, in the main, of a single type, with three or four regional modifications. The type rock is gray, moderately coarse in texture, and composed of feldspar, quartz, and mica, with few accessory minerals. The feldspar is white, chiefly orthoclase, with perhaps an occasional small amount of plagioclase. The orthoclase is often porphyritically developed, while the color varies locally, but rarely, to a faint pink. The quartz is generally granular. The mica includes both the black and white varieties, the former predominating, but showing considerable variation in amount. It is distributed irregularly throughout the mass of the rock, or is lineally disposed, when it imparts a more or less definite foliation. An accessory mineral is hornblende, in fine and coarse crystals, but on the line of reconnaissance its presence is local and somewhat rare. It occurred notably in the granite

of Trinity Range, 8 or 9 miles west of Rocky Bar, and again in conspicuously large crystals along the lower portion of Napias Creek, 20 to 30 miles west of Salmon City. In the latter locality a further modification of the type granite takes place in the development of the orthoclase crystals to an extraordinary size—from 1 to 3 or 4 inches in the direction of the vertical axis. The outlines of the crystals are usually somewhat rounded. On exposed rock surfaces the crystals weather in knobs, but fresh fractures extend through rock and crystals alike, often along cleavage planes of the latter, the rock then presenting the appearance of a more or less uniformly crystalline granular matrix sharply relieved by the smooth, brilliant faces of the porphyritically developed feldspar. To the granite of this description the designation "bird's-eye" may be appropriately applied.

A second departure from the type granite occurs in the precipitous walls of the Loon Creek Canyon, 3 or 4 miles below Oro Grande. Here the gray variety is wholly replaced by one of deep pink, derived from orthoclase of this color. A faint greenish tint is sometimes induced by the decomposition of the biotite. The texture of this granite is fine to coarse, and the grain even. The areal extent is undetermined, but it outcrops at intervals for several miles.

A third and local modification of the normal granite takes place in proximity to mineral veins. This consists in the loss of a very large proportion of the mica, the remaining feldspar and quartz constituting a somewhat conspicuous rock, by means of which the course of the vein may readily be traced, and which, in fact, may enter into the composition of the vein itself as "ledge matter." The clearest illustration of this occurrence is to be seen in the mining camps in the vicinity of Rocky Bar and Atlanta.

Typical gneiss occurs in some of the spurs of the Sawtooth Range, notably about the drainage system of Upper Redfish Lake. Wherever observed it has the mineral composition of the typical gray granite. In the locality referred to, the foliation is so complete as to create the impression of bedded strata, while the effect upon topographic lines is markedly that of an unaltered stratified rock.

The granites and gneisses prevail in the mountains of the western half of the State, while in the eastern they occur as range cores in connection with schists, quartzites, or limestones. None of the latter rocks, however, were encountered in the western half of the State.

ALGONKIAN.

To this is provisionally assigned the great series of micaceous, quartzitic, and chloritic schists of eastern Idaho. The reference is based merely upon lithological character and a resemblance to other beds in the Cordilleras which have already been so assigned. The series embraces, together with the schists, numerous beds of quartzite, and all have the general field appearance of clastic rocks. Many of the layers

contain a very considerable amount of carbonate of lime. The series in regions of strong development has a probable thickness of 3,000 to 4,000 feet, and is believed to be unconformable with the granite. In any event there was a time-break prior to the deposition upon the granite of the superincumbent strata, for the same series does not everywhere follow in the areas brought under observation.

The region of crystalline schists is distinctively the eastern half of the State, although in this portion are found also the Paleozoic measures, as well as the older granites forming cores of many of the ranges. The strongest development of the series observed on the route of reconnaissance was in the Continental Divide east of Salmon City, in the region of Big Creek and its tributaries, and in the range separating the drainage of this stream from that of the main Salmon. The series is also exposed at several points along the Salmon above Salmon City, notably, from a point about 9 miles above the city to one 18 miles above. It is then cut out by eruptives of undetermined extent; after a partially covered stretch of 10 miles it again appears along the river for a distance of about 2½ miles; eruptives again succeed, the schists finally disappearing in a small, disconnected outcrop near the mouth of the Pahsimeri.

Schistose rocks occur associated with the slates of Lost and Wood rivers, but it is somewhat doubtful if they belong, in their entirety at least, to the great series of crystalline strata just described. They are here apparently associated more closely with Paleozoic measures.

UNALTERED SEDIMENTARY ROCKS.

PALEOZOIC.

The succession of beds in southern Idaho is difficult of determination, owing, first, to a marked difference in their petrographic characters from recognized formations elsewhere in the Rocky Mountains, this preventing their assignment to a definite position in the scale of formations; secondly, to frequent interruptions of continuity by eruptives; and in the third place, to folds and faults.

Later than the granites, and probably also than the schists described above, is a great body of pink and white quartzites, of at least 1,500 feet maximum thickness. They are heavy bedded, hard, and uniform in texture and composition. Their greatest development is along the Salmon River from a point about 5 or 6 miles below the mouth of the Pahsimeri to within 6 or 7 miles of Challis. At the lower end of this stretch they are thrown into a prominent anticline, the eastern end of which is cut by the sharp gorge of the river, showing them in uninterrupted succession for 1,000 to 1,500 feet. Numerous other similarly disposed anticlines occur between this point and Challis, all in these measures. In none was Archean observed, and none was capped by higher strata of different nature. A small exposure of mica and quartzitic schists (Algonkian?) occurs just below the mouth of the Pahsimeri,

and although of the same strike as the quartzites on either side, they are separated from them by intervals of 3 miles or over occupied by eruptives or a Quaternary wash, and the relations between the two series are thus obscured. On Deer Creek, about 6 miles above its confluence with Wood River, is a local body of quartzite, which somewhat resembles those just described along the Salmon. It rests directly upon Archean granite, and is overlain by the dark-blue and black calcareous slates which form so important a feature of the Wood River district. The areal extent of this quartzite was not determined, but it is apparently small. A little south of Deer Creek it disappears with marked rapidity, the slates coming down on the granite. Similar quartzites probably exist in large bodies in the Salmon River Range also.

This quartzite is evidently to be classed with the older sedimentary rocks encountered; moreover, it closely resembles the established Cambrian quartzite of Colorado; on these grounds it is here referred to the Cambrian.

In the high range of mountains forming to the south the watershed of Wood River and to the north and northeast that of Salmon and Lost rivers are several thousand feet of quartzites, slates, conglomerates, calcareous shales, and limestones, which it has been impossible in the time available either to segregate into formations or to refer to definite ages. The range itself is the southeast extension of the Sawtooth, and carries some of the loftiest peaks in Idaho, notable among them being Mount Hyndman, 12,000 feet, 10 to 15 miles southeast of Ketchum. The range is an anticline, the core being gray granite, of the same type as that of the main Sawtooth, Trinity, and Boise ranges, and with a width of exposure along the Ketchum-Challis road of between 2 and 3 miles. Resting upon the granite on both the north and south sides of the range is the series of sedimentary beds mentioned above. The stratigraphic succession of the several members of the series is not confidently determined, and, moreover, there is an apparent difference in the succession on the two sides of the range.

On the north side, about the heads of the several branches of Lost River, quartzites and slates, dipping northeasterly, follow one another in quick succession. Black limestones are also present, and in some localities, not visited, they are apparently of considerable importance, judging from bowlders encountered in the valley. It is doubtful, however, if any single layer is more than a few feet thick. For 2 miles above East Fork of Lost River, large bodies of lava occupy both valley and hillsides, interrupting the series of sedimentary beds. Below East Fork, however, the quartzites and limestones, or at least quartzites with strongly calcareous layers included, reappear, continuing for 8 or 9 miles down the valley to the point where the road turns from the river northward toward Dickey. Within this distance the quartzites perhaps predominate, but black and probably often calcareous slates are

not infrequent. The calcareous nature of some of the quartzite layers is particularly marked a short distance below East Fork. For the lower 2 miles of the distance there occur in the series a number of conglomerate layers 1 to 10 feet thick. These are composed of a mass of cherty, subangular pebbles, and in the heavier beds, of quartzite and limestone débris in addition, the whole cemented by fine, granular material of the same nature. East of the Dickey road, after its turn northward from the valley of Lost River, what are probably sub-Carboniferous limestones appear in a prominent hill, a spur of the high range to the south. This limestone, which overlies the quartzite and slate series, outcrops in great bodies in the mountains to the north, forming the western periphery of the Thousand Springs Valley.

South of the Sawtooth Range, along Trail Creek and the Ketchum road, the succession of beds is somewhat different from that on the north side. Dark quartzites prevail immediately above the granite, followed after several hundred feet by a thick zone of light-colored, white and gray quartzites. About 6 miles from the summit the entire series is repeated, though whether in natural succession or by faulting was not ascertained. It is then overlain by several hundred feet of dark-gray and black slates or shales, probably often calcareous, which continue nearly to the mouth of Trail Creek Canyon. At this point the succession is interrupted by eruptives, which extend for a considerable distance along the Wood River Valley on its eastern side. West of Wood River, opposite Ketchum, is a heavy body of limestone, somewhat resembling in its massive character, its mode of weathering, and its general appearance the sub-Carboniferous of the Rocky Mountains, but the age was not definitely determined. This limestone is called by the miners the "gray limestone," in distinction from the "blue limestone," which occurs as thin beds in the series of shale overlying. The dip is here down the river (southward). The overlying shales are gray, dark-blue, and black, and carry numerous one-foot to six-foot limestone bands distributed through them. The thickness of this shaly series is estimated at 5,000 feet. It constitutes the principal ore-bearing series of the Wood River district, though the lower slates and quartzites occasionally carry mineral.

On Deer Creek, a tributary of Wood River from the west, an eruptive again cuts into the sedimentary beds and occupies the hills to the north of the valley for a mile above its mouth. Above this, however, quartzites come in, followed by a few hundred feet of heavy-bedded dark-blue limestones, which bear considerable resemblance, in texture, weathering, and general appearance, to the sub-Carboniferous. Black calcareous slates of the general character of those already described follow the limestones, and are in turn succeeded by granite, just above Warm Springs, 4 miles above the mouth of the creek. This succession of shales by granite is possibly due to faulting. The granite extends up the valley for about 3 miles, when 400 or 500 feet of the heavy-bedded

Cambrian-like quartzite succeed, overlain by blue and black slates and limestones similar to those noted farther down the creek. The quartzites of this second area of sedimentary beds did not appear in the first series, east of the granite at the Warm Springs. The dip of the series below the Warm Springs is doubtful; west of the granite block, however, it is westward, bending around gradually to the southwest and south at the head of Deer Creek and its tributary from the south, Red Cloud Gulch. The black shales and limestones of Deer Creek are undoubtedly a part of the general series which constitutes the leading formation of the Wood River district, but their horizon in the latter is undetermined. South of Deer Creek, east of Red Cloud and Narrow Gauge gulches, the blue calcareous slates are in direct contact with the granites to the east, the quartzite observed in the valley of Deer Creek having here disappeared. Whether faulting or nondeposition is the cause of irregularity in this succession of the beds is unknown.

It is possible that the foregoing series of rocks from the granite up, perhaps 10,000 to 15,000 feet in all, fall wholly within the Paleozoic—Cambrian and younger systems; but except in the case of the sub-Carboniferous and overlying shales, neither their age, division lines, nor intersuccession was satisfactorily determined. The heavy bed of white and pink quartzite on Deer Creek belongs, perhaps, to the Cambrian; the dark quartzite series at the head of Trail Creek, and the calcareous slates, quartzites, and conglomerates of Lost River—from an unknown member of which the one or two fossils collected have been determined by Mr. C. D. Walcott to be not older than the Trenton—are apparently of a post-Cambrian age; the sub-Carboniferous is recognized; but the overlying shales are, again, beyond a general reference to the Carboniferous, in doubt. Lithologically they bear a slight resemblance to the Weber of Colorado and Utah. In the entire Wood River district there is much and varied faulting as well as folding, and only work in great detail will effect a solution of the many geological problems presented.

The foregoing series doubtless occurs in many ranges to the east and northeast of the localities described, especially in the mountains east of the Thousand Springs Valley and of Lost River.

The sub-Carboniferous, which, of the Paleozoic series is most clearly recognized, is, excepting possibly in the Wood River region, represented by the massive blue cave limestone, so characteristic of it throughout the Rocky Mountain region. Its identification is based upon lithological resemblances and the contained fossils, although no collection of fossils was attempted. The thickness is between 100 and 400 feet. The limestone occurs in especial force in the several ranges between the Challis Valley and the main fork of Lost River, but it is said to be present in many localities in eastern Idaho. Its relations to underlying beds were unobserved except in a single locality, in the forks of Lost River, where it apparently succeeds the series of

calcareous quartzites, slates, and conglomerates described above. On the divide between Antelope Creek and Lost River it is overlain by drab calcareous shales resembling those in the Wood River district, though possibly less metamorphosed.

In the range of mountains forming the southwest side of the Warm Spring and Antelope valleys, just east of the Salmon River, are beds, possibly 500 to 600 feet in total thickness, which are partly quartzite, partly limestone, the latter pinkish-drab, massive, and somewhat resembling the Silurian limestones of the Colorado areas. In the hurried examination given them, however, no fossils were found. In this locality, also, on the lower flanks of the range, are numerous large hot-spring deposits, the springs being now extinct. At the eastern end of the range, overlying what from a distance is apparently the sub-Carboniferous limestone, are about 50 feet of red beds of unknown composition. Above these are several hundred feet of calcareous shales, the same as those already mentioned on the divide between Antelope Creek and Lost River. The Little Lost River Range east of the Antelope and Thousand Springs valleys is reported by prospectors as being composed of the sub-Carboniferous limestone and overlying shales, and from a distance this seems to be the case.

CENOZOIC.

This system is represented in Idaho by the great series of sedimentary beds underlying the Snake Valley and by others which occupy certain of the intermontane valleys. Paleobotanic evidence points to the Eocene or Miocene as the age of the intermontane sediments, and molluscan and mammalian remains to the Pliocene as that of the Snake River beds.

The materials of the Snake River beds were derived largely from the mountains to the north and south of the valley, though doubtless more or less detritus from the region of the headwaters has been commingled with the other sediments for its entire length. The material, in the western half of the State at least, is chiefly of granitic origin, consisting of quartz and feldspar grains, often with a kaolin-looking cement, slightly ferruginous. The prevailing rock is a fine to medium grained, friable, gray sandstone, but clays occur, and also conglomerates. The formation was examined only locally, and there are doubtless many variations.

Associated with the Snake River beds, and in some instances interstratified with them, are flows of the lava which in one locality or another is such a well-known feature of the Snake Plains. Apparently the outpouring of this rock took place, in part at least, while the sedimentary beds were still being deposited. The sedimentaries outcrop along the Snake River in bluffs from one hundred to several hundred feet high, and also occur in benches of considerable elevation next to the mountains both north and south.

The age of the Snake River beds is probably Pliocene. *Melania taylori* Gabb and *Lithasia antiqua* Gabb, together with an undetermined vertebra (carniverous), have been found by Mr. Arthur Foote, at Glenns Ferry, on the Snake, in Elmore County, and Prof. O. C. Marsh personally reports Pliocene mammalia from the same series of beds on the north side of the Boise River, a few miles below Boise.[1]

The intermontane valley of the Salmon and Lemhi rivers, in the center of which Salmon City is situated, is occupied by a considerable thickness of Tertiary beds, the materials for which were derived from the early formations of the inclosing ranges. These materials are, for the most part, of granitic or quartzitic débris, and the beds are either clays, sandstones, or conglomerates.

The clays occupy a large area in the center of the valley. They are light-green and red, forming a conspicuous feature in the landscape. The colors are in two zones, the red at the higher level, nearer the periphery of the valley, and possibly a coloration of later times. The clays are slightly arenaceous in some layers, in others distinctly sandy, carrying even occasional thin bands of sandstone or conglomerate near the top. This conglomerate is a mass of small, round, or lenticular pebbles of half-inch maximum diameter, chiefly quartzite. Near the same horizon are thin layers of hard, white or brown, homogeneous clay, which usually has an abundance of minutely divided vegetable matter through it, sometimes sufficient to render it lignitic. Here and there fragmentary stumps of trees are found in a carbosilicified condition.

The sandstones of this intermontane Tertiary series occur at the base of the measures exposed, just beneath the clay division, and in all are probably 400 or 500 feet thick. They outcrop in bold bluffs along the Salmon. Their material is chiefly quartz. They are light yellow or gray and for the most part massive, though in some layers thin-bedded and even shaly. The gray beds are usually the finer in texture, the yellow sometimes approaching a grit. The series carries plant remains, leaves, stems, etc., which locally are in sufficient quantity to form with the shale a lignitic band. In one instance, just below Salmon City, this carbonaceous matter is distributed through 4 or 5 feet of shales, forming a coaly slate, within which is a 6-inch bed of dark-brown, woody lignite. So far as at present exposed, this is not of economic value. Overlying the slate are 10 feet of sandstone, succeeded by 5 or 10 feet more of a very hard, moderately coarse quartzite-conglomerate, which is somewhat ferruginous, and often fractures across matrix and pebbles alike. Within a short distance of this outcrop is another exposure of a similar conglomerate, in appearance 30 or 40 feet higher up than the first, but not definitely so determined. This second conglomerate in particular bears a resemblance

[1]See also various references in Bull. U. S. Geol. Survey No. 84, Correlation papers—Neocene, by Dall and Harris, pp. 285 and 286. 1892.

to certain beds along the base of the Continental Divide in the vicinity of the Lemhi placer mine on Kirtley Creek. Just beneath this conglomerate bed, along the Salmon, are some white sandstones, more or less argillaceous and ferruginous, carrying kidney-shaped iron concretions, and leaf-bearing. Among the forms collected Mr. Knowlton has recognized—

Sequoia langsdorfii (Brong.) Ung.
Glyptostrobus europæus Brong.
Equisetum (?) sp.
Dicotyledons: Ficus (?), *Quercus* (?), etc.
Plant stems.

Mr. Knowlton adds the following remarks in the letter submitting the results of his examination:

Neither of the conifers can be relied upon to prove close questions of age, for they have a considerable vertical range. *Glyptostrobus europæus* is, however, absolutely, and *Sequoia langsdorfii* almost exclusively, confined to the Tertiary. Both species have a wide geographical range, and are very abundant forms. The first is abundant in this country in the Fort Union group, Upper Laramie (Fort Union) of Canada, Mackenzie River, Alaska, and Arctic Miocene in general. In Europe it is mainly confined to the Eocene and Miocene. *Sequoia langsdorfii* has been once reported from the true Laramie, but I regard this identification as extremely doubtful. It is very abundant in the Fort Union group, and is also found at the same places as the other. The Dicotyledons are fragmentary but seem to belong to such genera as Ficus, Quercus, etc. The Equisetum and vegetable stems are worthless for stratigraphic purposes.

The evidence, incomplete as it is, shows the Tertiary age of these beds, but whether they are Eocene or Miocene it is impossible to say.

In the bluffs of Kirtley Creek, about 1½ miles below the Lemhi Placer Company's bar, is the following exposure:

	Feet.
At top of bluff, obscured beneath Pleistocene gravel	20
Argillaceous sands	5
Pure sands, concretions at base	10
Coarse gravel	10
Bright-red clays, very pure	5
Red clays with pebbles finer than in the gravel above	5

Gravel probably still underlies, but it is covered.

The position of the beds is nearly horizontal, with a possible slight dip to west. Their relation to the other beds in the valley could not at the time be determined, but they are quite likely younger than the series of green clays, at one point, indeed, apparently resting upon them or a nearly allied stratum. Moreover, apparently the red clays everywhere occur at a higher altitude than the green.

The conglomerates of this series of Tertiary beds outcrop in great force about the periphery of the Salmon City Valley, especially at the west base of the Continental Divide, and are difficult of reference. Being auriferous, they are the most important, from an economic standpoint, of all the beds. They are exposed in the cuts of the Lemhi

Placer Mining Company on Kirtley Creek, about 2 miles from the base of the range. At this point the section given below was obtained.

The gravels of this section, Pleistocene and Tertiary, are made up of quartzites and schists derived from the neighboring mountains. The two are readily distinguished, the Pleistocene being loose, easily disintegrated, and carrying in the interstices of the bowlders and pebbles considerable earthy matter; the Tertiary gravels being a compact mass of large pebbles, up to 1 foot in diameter, in a grit matrix, the whole moderately hard and difficult to hydraulic.

The unconformity between beds *c* and *d* is evidenced not only by the wavy lines between the two, as shown in the sketch, but also by the fact that the gravel beds *c* rests successively upon several of the underlying beds. Both series of strata, however, those above and those below the line of unconformity, are alike flexed in the crumpling that has taken place in the region. The beds *d–f* are considered "bed-rock" by the

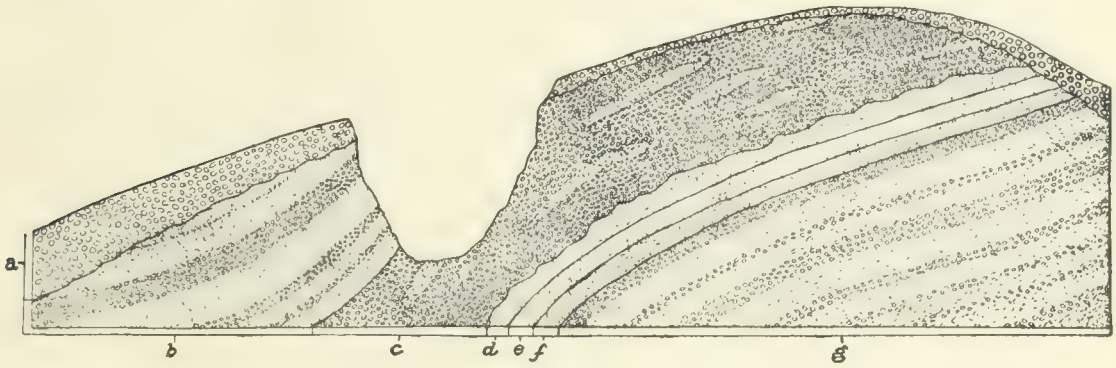


FIG. 38.—Section of Tertiary gravels at Lemhi placer mine.

a, Pleistocene gravel, overlying unconformably the Tertiary series, 0–10 feet; auriferous. *b*, Series of sandstones with some gravelly layers; average thickness, 30 feet. *c*, Coarse conglomerate; material, quartzite; 20 feet; unconformable with *d*; auriferous. *d*, Yellow sandstone; solid bed, 3 feet; leaf-bearing. *e*, White sandstone; solid bed, 5 feet; leaf-bearing. *f*, Very white sandstone; thin-bedded, fine-grained; 5 feet. (*d–f*, Bed-rock, of miners.) *g*, Series of sandstones and conglomerates in equal proportions; 15 feet show, but it extends below the present depth of the cut; auriferous.

miners, though the series below is said to be auriferous, even in paying degree under favorable conditions of water and work. The thickness of the conglomerate series is unknown; it possibly reaches 300 or 400 feet.

The Pleistocene cap to the series is, in part, probably, wash direct from the mountains, and in part, doubtless, the product of subaerial denudation of the Tertiaries.

On the hills of greater height on both sides of Kirtley Creek, at an altitude of about 200 feet above the stream, is a bed of coarse quartzite-conglomerate, very hard, fracturing across matrix and pebbles alike. Its relation to the other beds was undetermined.

It was impossible, within the short time available, to determine completely the relative stratigraphic position of the three or four varieties of Tertiary rocks described. The sandstones with their subordinate conglomerate beds, which outcrop in the bluffs of the Salmon River, are beyond question overlain by the green clays, and these in turn,

perhaps, by the bright-red clays and associated gravels outcropping in the bench lands north of Kirtley Creek, below the placer mines. Concerning the position of the conglomerate series at the mines, however, there is more doubt, for the strata underlying the area to the west were covered for a considerable distance by wash. The dip of the conglomerates at the mines is 15° to 50° westward, and they pass beneath the general surface of the long, gentle valley slope. If they are not brought up by flexures within a mile or two below the Lemhi placers, they are succeeded more or less directly by the green clays, and would therefore, in this case, correspond to the sandstone-conglomerate series along the river bluffs. Certain resemblances between the two have already been noticed. It is possible that they may wholly underlie the river outcrops, the latter sandstones perhaps being concealed nearer the border of the basin in the intervals of no outcrop.

The valley of the Payette River, at Horseshoe Bend, also carries a series of intermontane Tertiary beds, the materials for which were doubtless derived from the inclosing granite ranges. The series is in general a succession of sandstones with some clays and conglomerates, carrying plant remains which in some instances have been sufficiently abundant to form carbonaceous shales, in others coal itself. In appearance the Payette beds resemble those at Salmon City; in composition and their place of derivation they may be more closely affiliated with the Snake River series. Of their age, however, except that they are Tertiary, no evidence was obtained.

PLEISTOCENE.

This consists of gravels occurring along stream bottoms, of the products of subaerial disintegration, or of morainal débris. These deposits will not be discussed beyond mention in connection with other points in the report.

ERUPTIVE ROCKS.

The eruptive rocks of southern Idaho present a great variety of types, and their manner of occurrence ranges from a simple dike to a series of sheets surrounding a probable volcanic center or neck. The flows have probably taken place at many stages in the development of the region, from Archean, possibly, to late Tertiary, and even at the present day traces of volcanic activity remain in innumerable hot springs throughout the State.

Along the front of the Boise Range are eruptives of a number of types in dikes, irregular masses, and sheets.

Among the dikes and irregular masses is a boss of andesite in the bluffs on the north side of the Boise Valley, a mile above Boise. Prior to the erosion of the bluffs this andesite was overlain by the Tertiary sediments, in which there was a slight upward bowing. A portion of the andesite has been identified as of the augitic variety; it is dark-

gray and banded. The associated variety is light pink-gray and vesicular. The groundmass is, possibly, a devitrified glass, throughout which are small crystals of decomposing triclinic feldspar, and some magnetite. The interrelation of the two andesites was not determined.

About 5 miles east of Boise, in the granite of the Boise Range, near the edge of a prominent basalt flow, in the Flannigan prospect tunnels, are several narrow dikes of aphanitic syenite (lamprophyre), having a general trend of N. 50° to 70° W., with a dip of 45° to 80° SW., apparently coincident with the foliation of the granite. A vein of quartz with a slight admixture of granitic material lies between two of the dikes, at a little distance from each, and is said to be gold-bearing.

On the Boise-Idaho City stage road, from 2 to 3 miles above Boise, and just at the edge of the granite mountain slope, is an outcrop of rhyolites, of an area somewhat less than a square mile. The variety of rock most typical of the locality is, perhaps, a microspherulitic rhyolite, light-gray to faint pink, with small porphyritic crystals of sanidine and some quartz. This alternates with a mottled variety, pink and dark gray, with the same porphyritic development of crystals. Occasionally the groundmass is microcrystalline or cryptocrystalline, but it is more frequently glassy. Perlitic, spherulitic, and vesicular varieties also occur. Fluidal structure is common throughout the entire mass. The rhyolite cuts the gray granite of the Boise Range, forming an apparently irregular body, the maximum dimension having a northwest-southeast direction.

About 6 miles northeast of Boise, and north of the Boise-Idaho City road, in the slopes of the range, is a dike of quartz-porphyry running through the granite in a general northwest-southeast direction. The dike is not over 3 or 4 feet wide, and with the granite on either side has been prospected for gold.

A hundred yards west of the above outcrop, and also at two or three other points on the lower slopes of the Boise Range, notably one a little south of the Boise-Idaho City road, about 2 miles from Boise, are deposits of a brown, porous, stratified, rhyolitic tuff, carrying a large amount of angular and subangular granitic débris, in fragments up to 1 or 2 feet in diameter. The deposit occurs at various altitudes, but its relations to the Tertiary beds of the region are not clearly shown.

One of the most widely distributed of the eruptives is basalt. This forms a large part of the floor of the Snake Plains, and occurs in isolated sheets, bosses, and dikes at many points in the mountains. Prominent among these are two or three independent sheets on the western slopes of the Boise Range; an enormous flow along the South Fork of the Boise River within the mountains; others, very heavy, above the three forks of Camas Creek, a tributary of the Middle Fork of the Salmon; and several along the Salmon River between Salmon City and Challis. Of those on the western slopes of the Boise Range a typical occurrence is a remnant, a half mile in area, about 5 miles

east of Boise, 1,000 or 1,500 feet above the valley. The flow filled the early gulches and capped the intervening ridges, its surface acquiring a position of rest but slightly at variance with the general slope of the range. In later times the gulches have been recut to the granite beneath. Beyond the present limits of the flow no trace of connecting bed of basalt could be found; it was probably, therefore, a small isolated body, welling up through a local dike.

Between Slaters Creek and the Boise the basalt constitutes the floor of a high mesa which extends for 10 to 15 miles along the base of the mountains, with the appearance of having at one time been continuous with the lava plains of the Snake Valley. The mesa has a gentle slope of 2° or 3° to the southwest, the basalt resting directly upon granite. In the gorge of the Boise the basalt forms, for 4 or 5 miles from the mountains, sharp vertical walls, the columnar structure being well developed on both upper and under surfaces of the flow. The thickness of the sheet varies from point to point, averaging perhaps 75 or 100 feet.

Within the mountains the basalt follows the main Boise to the South Fork, passing up this nearly to Pine Grove, a few miles northeast of Little Camas Prairie. It is also reported on Moores Creek nearly to Idaho City. None is said to occur on the main stream above the mouth of South Fork. There appear to have been at least two distinct periods of flow, the remnants of which are attached to the canyon walls, and lie, one, 500 to 1,000 feet above the present stream level, the other but 50 to 200 feet above. Which is the older was not determined. Whether it would be possible, by descending the canyon from Pine Grove, to trace the respective flows continuously, or at least to trace a particular flow entirely through, can not be stated, but it is a peculiar feature of their occurrence that the different benches of basalt are everywhere found practically at about the same height above the present water level; they fall with the stream, impelling the belief that the lava once flowed through the canyon as does the stream of to day.

Smith and Little Camas prairies are two broad intermontane flats on the course of the South Fork, the sites of ancient valleys refilled to their present levels with basalt of the same flows as in the canyon. The canyon is recut to a depth of 1,000 to 1,500 feet, presenting cross-sections of the valleys, which, as regards the basalt, are the same as those of the canyon in general. The precise nature of the two great lava lakes is unknown. They are evidently near the source of the basalt, and the valleys filled by them seem to have been the receiving reservoirs, in part for a stream from a source farther up the Boise, in part for flows from fissures in some of the side valleys tributary to the basins, and, perhaps, at the outset, from fissures in the bottoms of the valleys themselves. From the lakes the flows continued down the early Boise Canyon to the open valley of the Snake, receiving from the tributaries on either side greater or less accessions. This was

eminently the case at Moores Creek, where the flows are very heavy. Some of the smaller access ons were doubtless from the valley of Rattlesnake Creek, two irregular and somewhat extensive basalt dikes occurring about the forks 2 miles above the mouth. Just below the forks of Smith Creek, also, is another dike of the same composition as the foregoing, but with diabasic structure. Indeed, in the region crossed by trail from Boise to the Trinity Lakes and Rocky Bar, basalt and diabase dikes are numerous. The most isolated occurrence of diabase is as a complex near the head of Falls Creek, outcropping on the lower slopes of the Trinity Range. The outcrop is several hundred feet across, of irregular outline, and forms a conspicuous red and blue patch in the gray of the mountain side. The dikes, both of basalt and diabase, all cut gray granite.

A gray quartz-porphyry showing a groundmass of micropegmatite with porphyritic crystals of feldspar was observed on the Boise from a point 2 or 3 miles below the entrance of the South Fork, to Trail Creek. Its extent beyond this is undetermined.

On the ridge north of the stream flowing from the Trinity Lakes the granite is cut by a body of quartz-diorite-porphyrite, of a finely crystalline matrix and porphyritic feldspar. Between here and Rocky Bar, a distance of 8 or 9 miles, there are several occurrences of this rock or the quartzless variety, diorite-porphyrite. Within the same region, also, are occasional dikes of basalt or augite-andesite, which, was not determined. In the Red Warrior camp, 2 miles southwest of Rocky Bar, is also a light-gray to white, finely crystalline or microcrystalline quartz-porphyry, similar to the Leadville porphyry. Grains of pyrite occur disseminated through it. The specimen examined was from the dump of an inaccessible tunnel by the roadside, a mile or so northwest of the center of the camp. From the quantity, one may infer it to be a rock of importance, at least for this mine.

In the Jim Blaine mine, a mile and a half east of Rocky Bar, there occurs a dike of basalt carrying a few rounded quartz grains. Its relation to the ore body was not altogether clear.

On the eastern side of the high divide between Rocky Bar and Atlanta, on the lower half of the slope, there occurs in the granite a succession of enormous dikes, 100 to 200 feet wide, of quartz-porphyry and a quartz-bearing syenite-porphyry, which extends northwest several miles across country. What were probably similar occurrences were seen at a distance in several of the ranges about Atlanta, but the localities were not visited. The prevailing trend of the ledges is east and west, a direction often observed also in the granite and ore bodies of the Rocky Bar and Atlanta districts. The dikes dip 45° or 50° N. to vertical. Between them is the ordinary granite of the country, often appearing like included masses. The quartz-porphyry is typical, a felsitic groundmass, with small irregular bodies of quartz and occasional small crystals of feldspar, the general tint of the rock being a decided pink. In the

quartz-syenite-porphyry, also pink in effect, the quartz is distributed sparingly through a finely crystalline groundmass, while the orthoclase is developed in prominent porphyritic crystals. The basic mineral is usually finely crystalline, and in aggregates mottles the rock a dark-green. The relation between the quartz-porphyry and the quartz-bearing syenite-porphyry was not determined, although they evidently occur in close association with each other.

In Montezuma Gulch, east of Atlanta, between a third and half the distance to the head, is a narrow dike of aphanitic syenite (lamprophyre) similar to that occurring in the Flannigan mines on the west slope of the Boise Range. Its lineal extent is unknown.

In the Monarch mine, on Atlanta Hill, is a narrow dike of probable decomposed syenite (lamprophyre), but the specimen collected was too much altered to permit satisfactory determination.

In the Tahoma mine is a dike of white, decomposed porphyry, also altered beyond identification. Its thickness varies from 25 to 50 feet on the several levels. In one or two places the vein has been slightly thrown by it. The general trend of the dike is N. 26° W.; the dip, southwest. All the eruptives of the Atlanta district not infrequently contain pyrite in minute crystals; the influence of the dikes upon the mineralization of the veins, however, is undetermined.

In the granites of the Sawtooth Range, on both the east and west sides, are frequent, narrow, fine-grained dikes of aphanitic syenite (lamprophyre), and what is likely a nearly related rock with porphyritic crystals of triclinic feldspar. Quartz-porphyry was also observed on the east side of the range in the slopes west of Upper Redfish Creek. A large body of this rock appears in a side gulch entering the main valley about a mile above the lake, and, from their appearance at a distance, similar bodies are believed to exist at various points along the range front.

Rhyolite (aporhyolite) occurs as a large irregularly shaped dike in a hill on the east side of the Salmon Valley, 10 to 12 miles above the sharp bend of the river to the east and 4 to 5 miles above the Lower Redfish Lake. The rock is banded gray and brown, the brown often having a glassy or resinous appearance, the gray being very close textured, and marked with fine striations, as though of flow structure. The prevailing rock of the country is the usual gray granite.

In the morainal débris about the Lower Redfish Lake, derived from the Sawtooth Range, besides the more common pinkish granite, there are numerous bowlders of quartz-diorite-porphyrite—a dark-gray rock with porphyritic plagioclase and much sanidine.

A large body of quartz-porphyry of greenish-gray groundmass with feldspar in prominent crystals forms a high hill in the forks of Valley and Stanley creeks. The general trend of the mass is north and south. On the east side of Valley Creek, about 4 miles above the mouth of Stanley, is a prominent body of quartz-bearing syenite-porphyry, the

groundmass of which is micropegmatite with a very small amount of quartz. The rock is greenish-yellow. The porphyritic constituent is orthoclase. Near the head of Valley Creek, by the roadside, are numerous small dikes of dark-gray, altered diabase, cutting granite.

The main Sawtooth Range was crossed only at one point, at the head of Upper Redfish Creek; but in the occurrence of eruptives in the débris from the portion north of this, and in the veinings that may be observed from a distance, there are evidences of a number of varieties, among which the quartz-diorite-porphyrite above described is an important type. The veinings mentioned may be seen in all parts of the main range, now as the chief mass of one of the rugged peaks, now in a broad band of color, running along the precipitous sides in contact with a pink-colored granite which here seems to constitute the mass of the range. North of Cape Horn the range has the appearance from a distance of returning to the gray granite as its chief constituent—the granite which occurred at the southern end where crossed and which is the prevailing rock of the great mass of mountains to the west. East of the Sawtooth the gray granite passes into the high range forming the divide between the main Salmon and its Middle Fork, and into the mountains east of the Salmon River and Valley Creek. In nearly every portion of its area, however, it is frequently cut by eruptives of one kind or another.

East of the trails to Sheep Mountain and Loon Creek, in the direction of Bonanza, great bodies of eruptives appear in the lofty peaks and intricate ranges there present. These were all beyond the route of reconnaissance. On the line of exploration, however, on the several heads of Beaver Creek, and in the gulch leading down to the mining camp of Sea Foam, are numerous dikes of diorite-porphyrite, crystalline-granular throughout, with porphyritic development of the feldspar. On Beaver Creek, also, is a white or light-gray, fine-grained variety of quartz-porphyry of frequent recurrence; magnesian mica is quite prominent throughout this rock. Other quartz-porphyries differing somewhat from the foregoing in the amount of quartz or the porphyritic development of their feldspar appear in dikes of greater or less extent in the mountains between Beaver, Bernard, and Loon creeks. On the latter stream they are particularly abundant. They all cut the granite of the region.

In the canyon of Loon Creek, 3 miles below Oro Grande, as dikes in a coarse, pink granite, occurs a finely crystalline quartz-porphyry of a color closely resembling that of the granite. The orthoclase of the eruptive may be porphyritic, while the quartz usually occurs in minute grains in the groundmass. Both granite and eruptive are conspicuous features of the region's geology.

In the same vicinity occurs also a dark-gray quartz-diorite-porphyrite of a totally different facies from the pink. The crystallization of this is in two or three degrees of coarseness, white feldspar crystals being

prominent, though not large. The rock is of extensive outcrop, and occurs in heavy masses, in places apparently resting upon the granite of the region; but such an appearance may be due to an inclined position of the dikes in the granite and to the relative position of their outcrops in the precipitous walls of the canyon. The rock again appears about 3 miles farther down the canyon, from which point it may be followed in continuous outcrop for a distance of 8 miles or more downstream—beyond Beaver Ranch—and to the east far toward the summit of the high divide between the waters of Loon and Camas creeks.

On the east side of this divide, along the West Fork of Camas Creek and on the western branches of the Middle Fork, is another dark-gray porphyrite with many feldspar and quartz crystals and containing numerous small fragments of dark-green rocks. A fluidal structure is clearly shown under the microscope, though in the hand specimen it would hardly be suspected. The rock forms the chief outcrop in the region mentioned, but a gray rhyolitic tuff is also present at intervals. Well down on the West Fork of Camas Creek is also a yellow to yellowish-red quartz-porphyry, outcropping in three or four heavy ledges 50 to 100 feet wide. This porphyry is in part solid, in part somewhat vesicular. Apparently it cuts the gray rhyolite, but their relations were indistinct.

On passing from the area of gray rhyolite and associated quartz-porphyry near its eastern edge, there appears at a point a mile and a half above the mouth of the West Fork of Camas Creek a second prominent series of lighter-colored rhyolites and rhyolitic tuffs in heavy beds striking about N. 15° E. and dipping 30° E. These beds are continued far into the mountains both north and south, and in a northern direction there appears at a distance a tendency in the strike to bend to the northwest, as though the series formed the eastern edge of a dome-shaped mass of eruptives. This, however, is indefinite. The relation of this second series to the dark-gray rhyolites and quartz-porphyries is unknown, their contact being covered at the point traversed, but it is quite possible that the tuff rests upon the gray rhyolites and is in turn overlain by the lighter rhyolites with which it is associated. The tuff is bedded, and consists of a soft, white, green, or purple matrix, with included angular fragments of rhyolite from a half inch to 2 feet in diameter. It is, at a rough estimate, 200 to 300 feet thick, and extends along the creek a distance of one-quarter mile.

Banded rhyolite of somewhat varying texture and solidity apparently overlies the tuff, occurring in nearly continuous outcrop for a half mile farther downstream. Other tuffs succeed, with their included rhyolite fragments, and a matrix rather less friable than that of the lower beds, forming the last outcrops along the West Fork. Across main Camas Creek from the foregoing series, however, and just below the Three Forks, is a very similar succession of outcrops, rhyolites and rhyolitic tuffs in alternating bands 500 to 600 feet thick, often repeated,

striking about N. 60° E., with a dip of 10° to 20° SE. Although this series is similar to that on the West Fork and may be the same, direct continuity was not shown. This series is continued with variation to the head of the East Fork of Camas Creek (Silver Creek), and beyond into the ranges bordering Prairie Basin on the west. On Silver Creek several varieties of the rhyolite appear, together with other rocks more or less nearly related. Most of them occur in heavy ledges, walling in the canyon with ragged, precipitous sides. On the north side of Silver Creek, a N. 60° E. strike and northwest dip are maintained by the eruptives for a distance of 7 or 8 miles up the creek. On the south side, in the high ridge southeast of the Three Forks, the general dip is southward, with more or less gentle flexing. On the upper portion of the creek strike and dip vary somewhat.

Of the foregoing rocks, the tuff is of widest occurrence, and on both sides of the divide between Silver and Panther creeks it occurs in heavy beds, underlying the summit itself.

The Middle Fork of Camas Creek was not examined. From the Three Forks, however, there could be seen a few miles up, between the two chief branches, an enormous butte of eruptive rock, appearing like the remnant of a great lava-flow. It is of a very dark-brown color, and at a distance resembles basalt. At other points in this canyon the eruptives of the East and West forks seem to prevail.

In the gravel wash in the vicinity of the Three Forks were two varieties of rhyolite (aporhyolite) resembling that found in the upper valley of the Salmon River. These may have been brought down any of the streams.

From the foregoing it is evident that the region about the Three Forks of Camas Creek for a radius of 15 to 25 miles has at various intervals in the past been one of intense eruptive activity. The series of rhyolites and tuffs extends entirely across the drainage system, and from the high divide on its south to fully 10 miles below the junction of the three main creeks. Beyond this area, particularly to the west, rhyolites and other eruptives still occur over vast areas; to the east, while present, it is not to such complete exclusion of the primary rocks of the country.

The high mountains forming the divide between Prairie Basin and Yellow Jacket Creek, a tributary entering Camas Creek several miles north of the Three Forks, are largely composed of granite and of quartzitic and micaceous schists having a prevailing strike between N. 30° E. and N. 20° W., and a dip generally away from the center of the range, though often very steep or even vertical. The slates, which alone were crossed on the route traveled, are frequently cut by eruptives, in some instances at angles with the strike and dip, in others coincident with them.

Among the eruptives are the following: At the entrance to Fourth of July Canyon, a massive body of pink, banded rhyolite, in appearance

a sheet 50 to 60 feet thick, with a strike north and south and dip E. 20°, about that of the schists of the locality. The sheet extends for several miles along the eastern front of the range, with little apparent interruption. About 2 miles above the mouth of the canyon is a second dike of rhyolite, 20 feet wide, with finely developed dull-yellow feldspar crystals, one-half to 1 inch long. This is confined between slates, with about the same strike as they, but whether with coincident dip is uncertain. One mile above this is another eruptive of similar nature, striking N. 25° W., cutting through the slates. The summit of the divide carries a prominent outcrop of andesite, containing hornblende, mica, and augite. This rock is pink and coarse grained, with a white feldspar particularly conspicuous, abundant, and evenly distributed. The outcrop extends for a considerable distance along the range, and has somewhat the appearance of an irregularly shaped dike, or, in places, of a sheet lying upon the summit of the range. About a mile and a half down the western slope of the divide, on the trail, is a narrow dike of coarse, yellowish-gray quartz-porphyry with much orthoclase in crystals averaging an inch in length, many of them twinned on the Carlsbad type. A trachyte, finely crystalline and yellowish-gray, occurs just beside the porphyry and to the west of it, of apparently about the same width as the latter. A second dike of trachyte, similar to the first, about 15 feet wide, occurs 2 or 2½ miles lower down the valley, striking N. 15° W. and dipping W. 70°. The inclosing quartzites here dip 70° E., but it is not certain that the dike cuts them at all points. Still another dike, of dark-gray quartz-porphyry carrying hornblende and biotite with microspherulitic groundmass, occurs just above the confluence of the two forks of Yellow Jacket Creek. The foregoing eruptives all cut quartzite and mica-slates of the same kind as those on the east side of the range. The strike of the schists on the west side of the range varies from N. 15° to 75° W., with westerly or southerly dip. The eruptives seem generally to follow them in strike, but in dip they sometimes have the appearance of cutting across the stratification. On the main Yellow Jacket Creek, between three-quarters of a mile and 2 miles above Yellow Jacket camp, are numerous dikes of rhyolite similar to that at the entrance to Fourth of July Canyon. The dikes form enormous outcrops on the mountain sides, and seem to have a general trend N. 15° E. with a westerly dip of 50° or more. The dikes cut the quartzites of the country, and are locally so numerous that the slates appear as included bodies.

The eruptive rocks of the immediate Yellow Jacket mining district embrace the following: A quarter mile above the camp, syenite, a fine-grained, yellowish-gray rock, occurring apparently as a thin band (dike) between strata of the schists, which constitute the country rock, and with them striking N. 15° E. and dipping W. 45°. Dikes of quartz-porphyry occur between several of the veins in the Columbia ground. They are usually narrow, but of undetermined lineal extent. This rock

is locally termed "porphyry" by the miners. A third rock, which occurs in numerous narrow dikes throughout the region, is a dark-gray mica-diorite. A fourth and oft-recurring eruptive is a syenitic variety rich in mica, known as minette; and a fifth, more hornblendic, is almost identical with the rocks mentioned above as aphanitic syenite. These rocks are typical of the complex group called lamprophyres by some petrographers. Their occurrence here is in various dikes, and they are regarded by the miners, whether correctly or not the writer can not say on personal observation, as indicative of an ore body near at hand. In local parlance they are termed "syenite." Usually, so far as opened, when occurring next to the veins they form their foot walls, while the quartzite of the country or one of the other eruptives usually forms the hanging walls. A sixth eruptive, capping the high ridge northwest of the Columbia mines, is a very coarse quartz-porphyry, of the same general character as that a mile and a half west of the Panther-Yellow Jacket divide. A seventh rock is an altered diabase, observed as a dike in the Yellow Jacket mine. The general trend of the dikes is with the strike of the slates and main veins, N. 60° E., with perhaps occasional local variations.

On Panther Creek, about a mile and a half below Fourth of July Canyon, is a small deposit of a soft, white tuff containing angular fragments of rhyolite and possibly other eruptives. Its derivation is unknown. Another and more extended area of the same nature occurs on Napias Creek a little below California Bar, where it forms the hills both north and south of the stream for a mile or more back. On Napias Creek, about 2 miles above its confluence with Panther or Big Creek, are coarse-grained syenites of two somewhat different types. They occur in apparently heavy bodies of undetermined outline in the bird's-eye granite of the region.

A half mile above California Bar, on the northern side of the creek, is a small dike of either pyroxene-andesite or basalt, green and pink in color, the latter probably representing a stage of decomposition. Other eruptives occur in heavy masses in the vicinity of California Bar, but time did not permit examination.

From the Salmon City Valley to the Pahsimeri, the canyon of the Salmon is for long intervals cut through eruptives closely resembling in composition and occurrence the series of rhyolites in the Three Forks region. At the entrance to the canyon, about 6 miles above Salmon City, are beds of fine rhyolitic tuff, yellow, green, and pink, dipping 10° or so north, downstream. Underlying, and forming the actual entrance to the canyon, are 500 to 1,000 feet of pink and gray, banded rhyolite, somewhat spherulitic, and of varying hardness. The dip is 15° to 20°, its direction varying between northeast on the east side of the river and northwest on the west side. In fact, from their position, the rocks of this series appear to belong to a volcanic dome the center of which is at some point considerably to the south.

Beneath the rhyolite, with same dip, is an equally thick, very dense, dark gray, banded rock, probably augite-andesite. Its exterior is usually green or pink, from the weathering of some contained mineral, possibly of chloritic nature. About 3 miles farther up the canyon the andesite is followed by a second rhyolite, which appears from beneath the former in a great half dome, dipping north. The rock is light gray, with a vitreous groundmass, and, like the other rhyolite, displays marked banding. The foregoing rocks constitute the mountain masses on both sides of the canyon to the highest elevations, the gorge cut through them being sharp and rugged.

Beneath the rhyolite last described is a heavy series of dark-gray quartzites (Algonkian?), which continue for 8 or 9 miles along the canyon to a point about 18 miles above Salmon City. Here an augite-hornblende-andesite abruptly cuts the schists, the rock varying from dark-gray to pink, with a microcrystalline groundmass and porphyritic feldspar. In this same vicinity, judging from fragments, is also a quartz-bearing porphyry, possibly related to rhyolite. The andesite extends along the east side of the river for at least a half mile, when it passes beneath quartzite débris from the mountains above. On the west side of the river, a mile above its lower edge, it is overlain for a short distance by 60 to 75 feet of lava, showing columnar structure. Between 21 and 22 miles above Salmon City, at the upper end of Edson's ranch, occurs a basic, often amygdaloidal basalt, almost free from feldspar, and carrying a green or red alteration mineral. Toward the lower end the outcrop pitches gently south, but changes to an equal amount to the north, or becomes horizontal, a short distance on. There are two varieties of the rock, one hard and dark-gray, the other pink, light, and vesicular. It appears more as a valley rock than one entering into the structure of the higher parts of the mountains proper.

About 28 miles above Salmon City, schists again appear on the east side of the river for 2 or 2½ miles, to be then again cut out by the basalt, which on the west side of the river has continued all along. At a point 31 miles above Salmon City another series of rhyolitic and closely related rocks appears from beneath the basalt, with a general pitch of 20° to 30° northward, or downstream. The eruptive first beneath the basalt is a banded, pink trachyte. This is apparently 300 to 400 feet thick. Beneath it, with conformable pitch, is a pink rhyolite, immediately succeeded by a brilliant-green volcanic breccia. The matrix of this last rock consists of coarsely crystalline or microcrystalline rhyolitic material; the fragmental components are either green or pink rhyolite, or possibly trachyte, an associated rock in this region. The fragments are small to large, angular or slightly rounded by attrition, and the pink variety of rhyolite or trachyte is occasionally found vesicular. There is, altogether, a close resemblance between the fragmental constituents of this breccia and the eruptives occurring in

association with it. Stratification is occasionally strongly developed in this breccia, notably at a point about 38 miles above Salmon City. The dip is to the northward, the strike bending between northeast and northwest.

The series of eruptives thus enumerated closely resembles, in field appearance at least, that observed on Silver Creek, 20 or 30 miles west. The succession of the various types may differ somewhat in the two localities, but similar composition, structure, and general occurrence are clearly perceptible.

The bright-green, rhyolitic breccia extends along the river, with but few interruptions, to the Pahsimeri Valley, a distance of nearly 12 miles, forming the canyon walls to a height of 500 or 600 feet or receding to more distant hills according to the extent of the erosion. It is occasionally cut by one of the other eruptives, or its continuity may be interrupted by an anticline of Cambrian (?) quartzite, common in the region between here and Challis. Three or 4 miles below the mouth of the Pahsimeri the breccias are capped by heavy lava-flows, probably of hornblende-andesite, a rock of frequent and conspicuous occurrence between here and the upper end of the Pahsimeri-Salmon Valley, 3 miles above the mouth of the former stream. In the latter locality the andesite abuts against a quartzite anticline, and also appears on the slopes of hills to the east at much higher elevations. West of the Salmon an old valley in the northern slope of the quartzite ridge is filled with eruptives, appearing at a distance to be partly breccia and partly andesite. These eruptives again appear south of this anticline, still abutting against the quartzites or capping the lower spurs of the ridge. From here they continue to the Challis Valley, forming river bluffs and adjacent hills. They surround the quartzite anticlines of this region, and, locally, rise slightly upon their sides. At the lower end of the Challis Valley, at the entrance to the canyon of the Salmon, the east bluff of the river shows several hundred feet of interbedded breccia and andesite, the layers often presenting uneven lines of separation, or wedging out entirely, all without semblance of regularity. Just back of the town of Challis is the last exposure of the breccia observed along the route.

It was impossible to delineate the area occupied by the breccias; their extent along the Salmon has been given—35 or 40 miles. East of the river they seem to be limited within a few miles (2 or 3) by the quartzites or other rocks of the Salmon Mountains, excepting, perhaps, along the Pahsimeri River, up which they extend for at least 4 or 5 miles, possibly farther. West of the Salmon the extent of the breccias, for the southern portion of their area at least, is considerably greater, possibly 5 or 10 miles from the river in some instances. The nature and configuration of the deposit as a whole are difficult to understand without detailed work. Rhyolites, andesites, basalts, and breccias are associated at one point or another, and, as in the region lower down

the Salmon and, again, about the Three Forks of Camas Creek, would seem to form yet another great volcanic center.

At the upper end of the Challis Valley, along the foot of the range inclosing it on the south, occur enormous bodies of a gray basic andesite containing both hornblende and augite and grading into basaltic varieties. Their outcrop on the river is several hundred feet in height and between 2 and 3 miles in length, and they apparently extend for a considerable distance into the hills on either side.

About 6 miles east of the Salmon River are several small exposures of greenish-gray andesitic or rhyolitic tuff dipping about 15° northeast.

The divide between Warm Spring and Antelope creeks is capped with a thin layer of bright-red rhyolite. The groundmass is homogeneous, and the porphyritic mineral, chiefly feldspar, at a minimum. The rhyolite overlies green and yellow tuffs, similar in appearance to those seen elsewhere in the Challis Valley. The entire series seems to have a gentle rise from periphery to center, forming a dome 2 or 3 miles across.

The Challis Valley abounds in eruptives of one kind or another that may be seen in outcrops, low domes, buttes, ridges, etc., scattered over the greater part of its area. It is preeminently an area of volcanic rocks modified by erosion and the deposit of materials derived from the inclosing ranges, sedimentary and crystalline.

In the Wood River Valley, both in the vicinity of Ketchum and for several miles above and below, are numerous dikes or other irregular masses of andesite, embracing the hornblende-mica and hornblende varieties, with feldspar porphyritically developed. The larger bodies are several miles in extent, showing in massive outcrops in the valley above the town, and below, extending well into the ranges west of the river. On Deer Creek, 8 miles below Ketchum, there is a small outcrop of andesite, but its continuity with bodies higher up the main stream was not proved. The general trend of the larger bodies of eruptives is north-northeast; the pitch, westward. The eruptives cut the great shale and limestone series forming the mass of the mountains in this district. They seem, however, to be quite independent of the ore bodies of the Wood River district, and therefore to have had little if any influence upon their mineralization; but the entire region is one of marked metamorphism and mineral impregnation.

A few miles south of the Wood River district lie the plains of the Snake River and its tributaries in this region. Among the latter, the valley of the Big Camas is underlain by heavy sheets of augite-andesite, which also extend to the higher lands along the base of the mountains both north and south. A prominent sheet appears along Camp Creek, extending from 1 or 2 miles below Doniphan to the mouth, resting upon granite, which is exposed at one or two points. The flow has a pitch to the south, as though acquired by the general inclination of the underlying surface. Bodies of this eruptive also appear to the

northeast of Doniphan. The ridge south of Camas Prairie, separating it from the Snake Plains, appears from a distance to be largely composed of augite-andesite, granite, by report, being the other constituent. On High Prairie, at the head of Big Camas Creek, are still other heavy outcrops of augite-andesite; and indeed it is quite likely that the entire floor between the granites on the north and south is underlain with it, though now covered with wash from the mountains.

These andesites are probably directly related in occurrence and composition to the basalts of the Snake Plains and of the Boise country a short distance farther west, and to those within the mountains to the north.

In the granite of the foothills between High Prairie and the Boise are several dikes of fine and coarsely crystalline quartz-porphyries. The dikes are narrow and have a lineal extent of not over 1 or 2 miles. Similar dikes have already been cited on the western slopes of the Boise Range and along the Boise Canyon within the range itself.

From the road from Nampa to Silver City, across the broad plains of the Snake, may be seen numerous exposures of basalt in sheets horizontal, or buckled in low dome-like elevations from a half mile to 2 or 3 miles in diameter and 100 to 500 feet high. Of the latter occurrence Initial Point is an illustration. In some instances erosion has begun to take effect at the center of the dome, probably from a greater abundance of cracks than elsewhere. Along the Snake, in the vicinity of this road, the lava shows in precipitous walls, resting upon the Tertiary beds which are exposed in the lower portion of the bluffs. South of the river, in both valley and mountains, are enormous bodies of eruptives of various types, in dikes, sheets, and irregular masses. In one or two localities certain of them carry opals of gem value.

The eruptive rocks of the De Lamar and Silver City district embrace rhyolite, diabase, and basalt. The country rock of the De Lamar mine is rhyolite of rather fine, even texture. The general color in the mines and in many places outside is white, but a darker, greenish variety also occurs. The extent of the rhyolite body is said to be about 5 by 3 miles, the greater dimension lying northwest-southeast. In the Black Jack mine the country rock is also rhyolite, very similar to that of the De Lamar mine, but whether of the same body was not ascertained. The rhyolite becomes highly kaolinized in a certain part of the mine, and is then mistaken by the miners for granite, and is so called. Diabase, called by the miners "trachyte," also occurs as a dike in the Black Jack mines, and basalt appears as a surface flow a half mile below the mine on the mountain side. The occurrence of these eruptives and their relations to one another are somewhat obscure, except that the diabase and basalt are later than the rhyolite.

The effect of the eruptives upon the mineralization of the ore bodies will require detailed observations in field and chemical laboratory. The rhyolite near the veins nearly always shows some degree of mineralization.

GENERAL STRUCTURAL FEATURES.

The mountains of the southern half of Idaho are developed en masse or in ranges the lines of which have a north-northwest or an east-northeast direction. The development en masse is confined to the western half of the State; the system of ranges, although not confined to the eastern, is nevertheless its chief order of structure. In the mountains en masse it is quite probable that the elevations were attained in pre-Paleozoic times, while the range system may have undergone several periods of development, to late Tertiary.

The range of primary importance is the Continental Divide. This pursues a somewhat irregular trend along the State's border, but east of the Lemhi and Salmon valleys for a distance of nearly 100 miles it has a general course between N. 30° and 50° W., which is also that of its structural axis. The quartzites and schists showing in its western face are locally crumpled, but the prevailing dip is 50° or 60° SW. Regarding the nature of the uplift, it is believed to be an anticline, but time permitted an examination at only one point on the western side.

The development of the Continental Divide, and also of the ranges to the west, has doubtless continued in varying degree from early times to the Miocene, for nonconformities occur within the crystalline series, and in the Tertiary beds of the Salmon City Valley folding of considerable importance may be seen, along both the Lemhi and Salmon rivers, and east of them, in the region of Kirtley and Carmen creeks.

Parallel with the fold of the Continental Divide in Idaho are numerous others, represented in the Lost and Salmon River ranges and those immediately to the west. The greater part of these ranges lay so far beyond the route of survey that their structure could be seen only remotely. Their northwestern ends, however, were in many instances observed along the Salmon and Lost rivers in the passage from Salmon City to Wood River.

The general strike here encountered was about N. 35° W., the dip now northeast, now southwest. This is shown in the areas of Algonkian (?) schists and quartzites between Salmon City and the Pahsimeri, and in the several anticlines that occur in what have been provisionally regarded as Cambrian quartzites, extending along the Salmon River from a point 10 or 12 miles below the Pahsimeri to Challis. Many of the anticlines, having been cut by the river near one end or the other, show both exterior and interior structure, presenting canyon walls sometimes in sheer precipices 1,000 to 1,500 feet high. While the majority of the folds passed are anticlines, others are quite possibly monoclines, the result of faulting, though this was suggested rather than proved by minor strike faults and by the general configuration of some of the ridges observed.

In the mountains of the Wood River region the development is again upon a N. 30° W. trend; the structure is anticlinal, the axis of elevation passing east of the river, in the mountains between this and the Lost

and Salmon rivers. The northern extent of this anticline is unknown; to the south, as observed from a distance, it apparently sinks beneath the Snake Plains. Between the Wood River ranges and the main Sawtooth, about the head of Salmon River, is a complexity of folds, the details of which could not be deciphered from a distance.

In the region thus far described the folds which have governed the range structure are particularly clear by reason of the presence of the sedimentaries, altered or unaltered. In the region of granites to the west, however, structural lines are more indefinite, but northwest-southeast trends, with dips to southwest or northeast, may still be found in sufficient number to warrant the belief that certain of the ranges, at least, were developed on the same lines as those, more pronounced, in the eastern portion of the State. Among these are the Sawtooth and Boise ranges, although the former has been greatly influenced by the texture of the rocks entering into its composition. Still, even the lines due to this influence were probably governed originally by the direction assumed in the fissuring, which controlled the trend of the rocks of eruptive origin. This is particularly noticeable along the crest of the Sawtooth.

An east-northeast structure is suggested at many points in the granites of the western half of the State. It is often but incipient, shown chiefly in lines of jointing, in occasional strikes of foliation planes, or in the trend of fissures, but the constant recurrence of these features indicates its prevalence, and that the forces which produced it acted with greater or less energy over a large portion of the western half of southern Idaho. Many local instances of the lighter effects occur about Rocky Bar and Atlanta, but the most pronounced illustration is the transverse ridge which forms the divide between the main Salmon and its Middle Fork. This ridge is an east-northeast anticline, the strata, whether granite or schist, quartzites or limestones, all showing the dip away from the center. The structure is traceable, with some obscure intervals, to the drainage of Camas Creek, within a few miles of the Yellow Jacket mining district. The interruptions are due both to complex folding and to the presence of large bodies of eruptives.

The divide between the waters of the Salmon and Snake rivers can not properly be considered a range in a strictly structural sense, for it is evidently composite in character. For 40 or 50 miles east of the Saw tooth it is probably a complex of folds. East of this it is formed by the transverse links between the several ranges of northwest trend, or by the ranges themselves, and to this combination is due the extraordinarily irregular trend of one of the most important watersheds of the State.

West of the Sawtooth Range, with one or two exceptions, the loci of the divides between the drainage basins are doubtless partly due to early accidents of structure—folding, faulting, jointing—but in the wide distribution of the homogeneous granite the structural features are only slightly pronounced and erosion has exerted its full influence

in modeling the configuration of to-day. The Boise Range, however, is clearly developed on northwest-southeast lines of structure, a part of the general system of the State.

The intermontane valley at Horse Shoe Bend, Payette River, like that at Salmon City, shows several flexures in its Tertiary beds. The most important is an anticline running diagonally across the center of the valley southeast to northwest, the other folds being subordinate to this, but developed in the same lines.

The ridge between the valley of Big Camas Creek and the Snake, which has a nearly east and west trend for 50 or 60 miles, shows from a distance a number of broad, gentle flexures, but their axial lines were not clearly visible from the route of travel. The western half of the ridge, at the head of Little Camas Creek, is a part of the general system of elevations which belongs to the mountain region just north.

The Owyhee Range in southwestern Idaho belongs to the type of Desert Ranges. It is of granite, cut by eruptives, with Pleistocene and probably Tertiary sediments occupying the small interior valley of Reynolds Creek. The sedimentary beds show slight folding, indicating movement in later times, but the range received its greatest development prior to the Tertiary.

MINING DISTRICTS.

GOLD AND SILVER.

The mining districts of the precious metals visited in the reconnaissance include the region about Rocky Bar and the adjacent Red Warrior camp, together known as the Bear Creek district; the celebrated Atlanta lode and its attendant veins; the Yellow Jacket camp; the California Bar, Leesburg, and Lemhi placers; Wood River; and the Silver City and De Lamar camps in the Owyhee Range. All are gold or silver producers in varied degrees, and have histories dating back from five to thirty years, with yields reported in some instances as enormous. At the present time the industry throughout the State is, with a few conspicuous exceptions, at a low ebb.

THE BEAR CREEK DISTRICT.

Under this are included the Rocky Bar and Red Warrior camps and the region immediately about—in all, an area 3 or 4 miles in diameter. Placers formerly extended along the main stream to points considerably beyond, but are now worked by a few Chinese only. The town of Rocky Bar lies well within the southern limit of the great mountain mass of Idaho, in a deep, narrow gulch near the junction of Beaver, Steel, Feather, and Bear creeks, from the latter of which the district receives its name. The elevation at Rocky Bar is 4,800 feet; the surrounding ridges rise to 6,500 feet; the crest of the divide between this and the Atlanta district, to 8,500 feet; while Mount Steel, the highest peak of the region, attains an altitude of 9,500 feet. Communication is by a good wagon road to Mountain Home Station, on the

Oregon Short Line, 61 miles distant. Red Warrior Camp lies from 1 to 2 miles southwest of Rocky Bar, about the heads of Red Warrior Creek, a short tributary of Bear Creek. The dividing ridge between

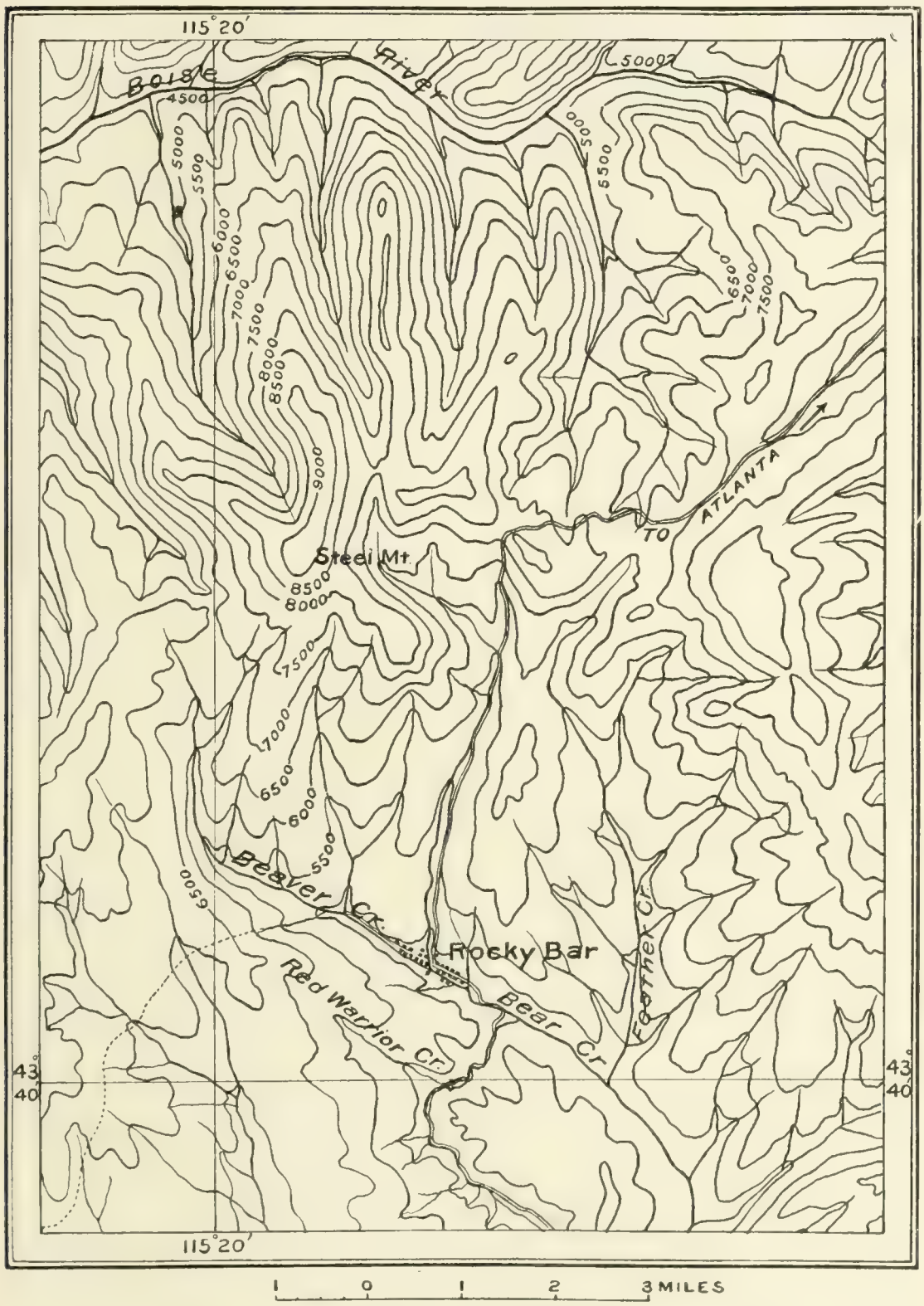


FIG. 39.—Sketch-map of Bear Creek district.

the two camps is 500 to 1,000 feet higher than Bear Creek, and has a general trend northwest. A wagon road leads from the camp to the main thoroughfare from Rocky Bar, following the stream.

The country rock of the district is the gray granite entering so largely into the constitution of the Boise and Sawtooth ranges. It is an aggregate of feldspar, quartz, and mica, chiefly biotite. The feldspar occasionally becomes porphyritic. The granite is inclined to the massive form, but it is not altogether devoid of foliation, which in some instances strikingly suggests bedding. The prevailing strike of the foliation planes is N. 50° to 70° E., while their dip is generally toward the northwest. Minor flexures, however, occur and the entire country displays more or less fracturing, especially along the gulches.

Eruptives occur as narrow dikes in the granites. They include basalt or olivine-diabase, quartz-porphyry similar to the Leadville porphyry, and diorite-porphyrite. These eruptives were found at many points along the route of survey in localities not noted for the presence of ore bodies, and their occurrence in a region of metalliferous veins, notwithstanding they contain locally a greater or less amount of finely disseminated sulphide of iron, may have been quite without influence upon the mineralization of the district; indeed, their mineral contents may have been derived from the same source as those of the ore bodies. The quartz-porphyry of Leadville type which occurs in a tunnel in Red Warrior Gulch a short distance above the camp, and perhaps at other points as well, is particularly rich in pyrite.

The mineral veins throughout the Bear Creek district are of quartz, carrying auriferous sulphides below water-level and their alteration products and free gold above. Most of the veins strike and dip with the foliation planes; occasionally, however, they may be found crossing these. In width they occur up to 12 feet, or in some places there may be a number of small veins, separated from one another by narrow bands of granite, the whole forming a single mineral-bearing zone 5 to 10 or 15 feet wide.

The included granite, and also that for 4 or 5 feet on either side whether of zone or single vein, usually shows a marked change in appearance. The micaceous compounds, particularly the biotite, have suffered greater or less decomposition, with dissemination of the iron throughout the rock mass, and the feldspars have become kaolinized in considerable degree. The granite appears, in fact, as a crystalline aggregate of feldspar and quartz, more or less ferruginous and disintegrated. This is commonly designated "vein matter." Such a zone of alteration is visible not only in open cuts and mines but frequently with great distinctness along the outcrop of a vein.

The quartz is coarse to finely crystalline, occasionally banded, and carries the mineral either disseminated, or in bunches, or following the planes of structure in thin seams. The material varies in richness of impregnation and the sulphides themselves in gold contents. The prevailing sulphide is pyrite, but those of antimony, zinc, galena, and copper are also present. The last is rare, and the zinc and galena sulphides are of minor importance.

The gold of the district is light colored and is said to be worth about $14 per ounce, the ore running from $6 to $30 per ton without concentration.

The openings in the Red Warrior camp, with the exception of the Wide West, which has been closed during the past season, are hardly more than prospects, developed by tunnels. The veins usually follow the planes of foliation, the prevailing strike being between northeast and east, varying slightly. At one or two points a crushed condition of the granite was observed, with what appeared to be numerous small and irregular gash veins. A suspected dip of the fractured zone was 80° NE.

The mines about Rocky Bar embrace some of historic interest—the Old Alturas, Idaho, and Vishnu—while the placers in early days were almost phenomenal in their product. At present the industry is quiet, and although a depth of 700 feet has been attained in some of the mines, only the upper levels could be examined. Quartz veins occur singly and in zones; in the former case, of widths up to 5 or 6 feet, locally even greater; in the latter, including intervening granite, up to 20 feet, the entire zone being mined. The latter condition prevailed, it is said, in the Old Alturas mine. The trends of the veins in this camp vary, but one between northeast and southeast prevails; the dip is usually south, though in one or two instances north. The upper portions of the veins are sometimes broken over in one direction or the other, dipping as low as 30°; in the lower levels the dip is said to be nearer vertical.

THE ATLANTA DISTRICT.

This district lies 18 miles northeast of Rocky Bar, across the divide between the South and Middle forks of the Boise River, at the junction of the latter stream with the Yuba. The center of mining interest is Atlanta Hill, an eminence of 1,500 or 2,000 feet in the forks of the streams, the end of a spur from the Sawtooth Range to the east. The town of Atlanta lies in the valley of the Middle Fork, at the northern base of the hill, 5,500 feet above sea-level. From this side three gulches enter the valley, Montezuma to the east, Quartz in the center, and a short, nameless one to the west. The first two head quite at the crest of the hill. The southern face of the hill is not so deeply eroded, and at its base Grouse Creek flows in nearly direct line to the Yuba. Confined to the hill, so far as at present known, is the celebrated Atlanta lode and its associated fissures. At the east both hill and lode seem to end abruptly against a higher portion of the spur, while to the west, beyond the Yuba, the presence of the lode has never been definitely established. South of Atlanta Hill, beyond Grouse Creek, the mountains, still spurs of the Sawtooth, rise to heights of 9,000 feet, forming the divide between the Yuba and South Fork of the Boise. North of Atlanta, across the Middle Fork, uniting Greylock (9,000 feet) and another lower peak to the west, is a prominent ridge capped with

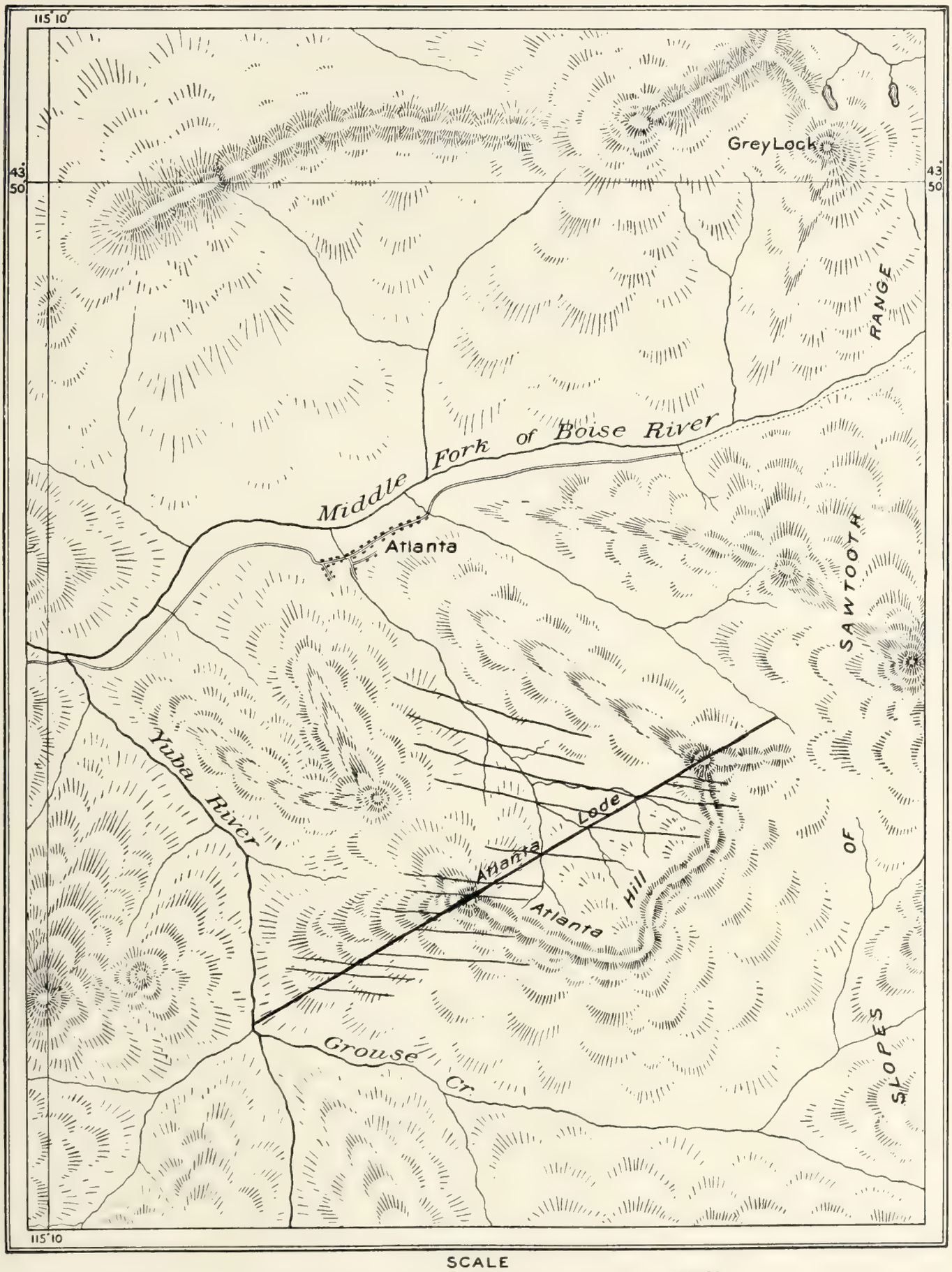
morainal or other drift, the crest fully 2,000 feet above the present level of the river. The Atlanta Valley is a gravel flat 3 or 4 miles long by 1 or 2 wide. The mountains about are sharp and rugged, the canyons often impassable, with evidence of glacial action in nearly all their upper portions. The district is 50 or 60 miles within the southern limits of the great mountain mass of Idaho, and but for a good wagon road to Rocky Bar and thence to Mountain Home Station on the Oregon Short Line, would be difficult of access. Trails lead from Atlanta to mining camps about, among them Sawtooth City and Vienna, in the upper Salmon Valley. The latter places are connected by wagon road with the Wood River region, about 40 miles distant.

The country rock of the Atlanta district is gray granite. It is similar in composition to that of the Bear Creek district, but structural planes or planes of foliation are not so prominent as there. To the west and east, however, gneissoid granite does occur, and on the eastern side of the Sawtooth Range are some very fine examples of this type of rock. The rock of the Atlanta district affords many evidences of extensive fracturing, and it may be that to this is due the difficulty of recognizing planes of foliation.

The eruptive rocks of the region occur in dikes of greater or less prominence. In the range west of the Yuba and Boise rivers, and also in the high point in the elbow of the latter stream, are a number of dikes 100 to 200 feet wide, of fine to coarsely crystalline, pink quartz-porphyry and quartz-bearing syenite-porphyry. These extend several miles across country, their general trend being a little north of west, their dip 45° or 50° NNE. to vertical. Aphanitic syenite (lamprophyre) also occurs in a small east-and-west dike in Montezuma Gulch, halfway up, and again in the Monarch mine in Quartz Gulch. Other dikes of the same or different nature are reported cutting the Atlanta lode in the various mines, but they were all inaccessible. In the Tahoma mine, which is on one of the lateral fissures, a dike of white decomposed porphyry, 25 to 50 feet thick, cuts the vein at a very acute angle. Its trend is N. 26° W.; its dip, W. 45° to perpendicular. On some of the levels it has thrown the vein, but this is again brought into line within 50 or 60 feet by a second fault, approximately parallel with the dike, marked by a clay course.

The influence of the several dikes of the district upon the mineralization of the veins has never been ascertained by those who have had charge of the mines, and the time allotted to the reconnaissance, together with the inaccessibility of many of the mines, did not permit the examination requisite for the solution of such a problem. The dikes are evidently outflows of several periods, and assumed many directions of trend.

The central feature in the Atlanta district from the mining standpoint is a main lode having what appear to be numerous nearly parallel branches, spurs, or feeders, forming acute angles with it; at the ends



SKETCH MAP OF ATLANTA DISTRICT.

the lode itself may split. The main lode is known as the Atlanta; the spurs are designated by the names of the several mines located upon them. The outcrop of the Atlanta lode has an almost uniform trend of N. 50° to 60° E., and occupies a position on or near the summit of Atlanta Hill, running nearly with the ridge. Its eastern end is supposed to be near Montezuma Gap; it follows thence westward along the crest of the ridge to the drainage of Quartz Gulch, which it crosses about one-fourth to one-third mile below the summit, and again taking the ridge, continues on the crest to the western slope, down which it passes to Yuba River. The total length of the lode exposed and prospected is 2½ miles; its continuation beyond this has not been proved. The width of the lode is said by those conversant with its early exploitation to vary between 50 and 150 feet, 75 being regarded a fair average for the whole. This width was the maximum observed by the writer, but only a very small portion was accessible to him. The lode is at present divided between four or five companies: one, of which Gen. W. H. Pettit is the manager, at the eastern end, owning 1,500 or more feet; a second, controlling a few feet only, coming next; the third, the Monarch, extending to Quartz Gulch; a fourth, the Buffalo, to the west of this; and the fifth, now the Atlanta Consolidated Gold and Silver Mining Company, occupying several thousand feet at the western end. The dip of the Atlanta lode varies in direction. At the eastern end it is to the N. 70° or 80°, becoming vertical at the western limit of the Pettit mine; in the Monarch mine a change to the south takes place; in the Buffalo the dip continues S. 45° to 70°; while for the western fourth of the lode, the position of the vein is again vertical or with but a slight southerly underlay.

The vein matter of the Atlanta lode is a more or less fragmental, clear to bluish-white quartz, and an altered granitic rock in which quartz predominates and the feldspars are highly kaolinized and the micas have generally disappeared. This second rock is doubtless related to the country granite, and has undergone the changes so common in rock adjacent to or in mineral veins. More or less clay is present locally, and some calc-spar in lenticular bodies. The entire mass of the vein is very friable and easily mined. The quartz is the chief metal-bearing constituent, and occurs from a thin seam to one 6 feet across, in one or several courses, on either wall or in the interior. Although a considerable proportion of the vein may contain ore in pay amount, it is said to be rare, if ever, that the entire width is mineralized to this extent. Again, it is often the case that narrower streaks contain as large amounts of gold and silver as the broader. The granitic ledge matter shows mineralization, but is usually regarded as too low in content to pay for mining. The calc-spar is considered by some miners as a good indication of proximity to a rich ore body.

The ore, according to General Pettit, who has been familiar with the lode from its earliest exploitation, lies in shoots, four or five in

number, along the length of the vein; one in the mine at the eastern end of the lode; one in the Monarch, pitching westward, toward the dike occurring near its shaft; one just beyond this dike, also pitching toward it, or eastward (this in the Buffalo mine); and one or two in that portion of the ledge now being opened by the Atlanta Consolidated Gold and Silver Mining Company. Moreover, in these shoots, the ore is said to be in the form of larger or smaller lenticular masses, which overlap one another in depth, occupying different positions in the width of the vein.

The Atlanta lode has the appearance of an original fissure the filling of which has been crushed by reason of movements belonging to a second period of disturbance. Mineralization may have been effected either at the time the original fissure was filled or subsequent to the fracturing that resulted from the second movement. The walls of this lode are horizontally, diagonally, or vertically slickensided; there is often present a strong clay selvage—almost always a trace of it; and the vein matter has been rendered friable by a marked degree of fracturing, the sharp, angular fragments often forming a brecciated mass, held together in a clay of fine siliceous cement. Slickensides and clays are also present in the interior of the vein.

The mineral contents of the vein are free gold and an auriferous sulphide of iron—pyrite or the related arsenical and antimonial compounds. Prof. J. E. Clayton,[1] from an early and more complete examination of the lode—chiefly, however, in the Monarch and Buffalo mines—reports the metallic contents as "gold, native silver, ruby silver, brittle silver ore, and sulphide of silver and pyrite. The brittle silver, or black antimonial silver, is the most abundant ore. Next in quantity and value is the ruby silver. The native silver and silver glance are found only in small quantities. The free gold constitutes from 20 to 40 per cent of the total value. The other minerals are iron pyrites in moderate quantities disseminated through the granular, friable quartz and the granitic inclosures of the lode. I saw but few traces of copper, zinc, or lead." Professor Clayton also adds, as the result of his observations, that "much of the quartz in this lode is comparatively barren. The rich streak of black sulphuret and ruby ore [probably in the Monarch and Buffalo mines] varies in width from 1 foot to 6 or 7 feet, and alongside of it is a zone of pay rock, equally as wide, that carries a good percentage of free gold with silver ore disseminated through it, making the pay streak from 2 to 15 feet wide and extending in length underground, in the Monarch and Buffalo claims, nearly 2,000 feet on the course of the lode." The character of the ore is said, however, to show material changes in the length of the lode.

As worked at the present day the average yield of the lode is about $20 per ton in gold. From this it varies in either direction. Ten

[1] Trans. Am. Inst. Min. Eng., Vol. V, p. 471, 1876–77.

dollars is regarded as the limit of profitable working, while bunches of ore of a value of several hundred dollars per ton are occasionally met with. The ore is now hand-sorted, a portion being milled in the camp, a portion concentrated and shipped out. In the early days, however, no effort was made to save ore, even the richest, that would not mill free gold; many of the dumps at the present time are therefore correspondingly profitable, and every season a portion of them is reworked by hand jigging or some other simple process.

The average proportion, in values, of gold to silver in the ores of the main lode is as 1 to 2; in the lateral veins north of the main lode, also as 1 to 2; but in some at least of those south the proportion is said to be as 3 to 1.

The fissures in Atlanta Hill transverse to the main lode have an E.W. to N. 65° W. trend, and dip north, south, or vertical, but always steep. Their structural relations with the lode are undetermined; some of them have the appearance of spurs, offshoots, or "feeders," while others may prove to be independent veins. They lie both to the north and south of the main lode, and those on opposite sides are in some instances so nearly continuous in their course that they may readily be suspected of being one and the same fissure. In no instance, however, has the passage of a lateral vein into the main lode been traced, except perhaps in the Pomeroy-Last Chance. Here General Pettit states that, with other objects in view, he traced the lateral directly into the main fissure, without a separating wall of any kind, the ground in the acute angle of the two veins being highly fractured.

The lateral veins rarely attain a thickness greater than 8 or 10 feet, and often but 1½ to 2 feet, or even less. Some of them are very rich in metallic contents, and carry mines of much importance. Among these are the Last Chance, Big Lode, and Tahoma, the first being to the south of the main lode, the others to its north. The ore of the lateral veins in a general way is similar to that of the main lode, consisting of free gold, native silver, and the sulphides already mentioned, in a quartz vein-stuff. Not all of the spurs show a fragmental, breccia-like character in the filling to the extent seen in the mines of the Atlanta vein, but the feature is not absent. The value of the ore of the transverse veins is said to vary considerably in the different mines, certain of them presenting material of low grade but of steady occurrence; others, material of high grade in smaller and more intermittent bodies. The relative proportions between the metallic contents also vary in the different veins, not only on the same side of the main fissure, but on opposite sides.

The Atlanta lode and its branches have yielded in past years enormous sums, and a favorable inference may well be drawn from history and observation as to the possibilities in the future. The lode is well located with regard to economic development, while timber and mining supplies may be obtained with comparative ease.

THE SHEEP MOUNTAIN DISTRICT.

This district is in the heart of one of the highest and most rugged mountain regions of Idaho. It is accessible only by trail, though a good mountain road is possible via Beaver and Bernard creeks from a point on the State wagon-road in the vicinity of Cape Horn. The center of the district is a hill 7 or 8 miles down Bernard Creek, north of the divide between the upper Salmon and the Middle Fork. The periphery of the district, however, includes the divide, and along this there has been considerable prospecting; owing to misinformation, it was the only locality visited, and the following description refers entirely to it.

The country rock is gray granite and quartzitic and micaceous schists, which in some layers are strongly calcareous. The schists occur both in series by themselves and as included belts, 1 to 100 feet or more wide, in the granite. The latter is more commonly the occurrence on the summit of the divide, while the schists in series are found chiefly on the northern slope. The bands of especial interest here are those in the granite. They may be traced for a mile or more, or may disappear after a few hundred feet, seeming to occur as irregular, isolated bodies. This appearance may be due to original differentiation in the material from which the granites and schists were derived or to included masses through faulting, the former perhaps being most plausible. The strike of schists, and of the granites where they show foliation planes, varies to all points of the compass, N. 15° to 35° W., N. 60° E., and east and west, being most common. This variation is due to local flexures, evidences of which are constantly recurring. The dip of the series in the divide is to the west or south, usually at a high angle.

Diorite-porphyrites and quartz-porphyrites occur in dikes throughout a large territory about. In the immediate region examined the quartz-porphyrites are most common; their trend is often with that of the slates, though occasionally across it. They occur, in some instances, in proximity to, if not immediately next, the ore-bearing slates; in others they are at a distance. Their influence upon the ore bodies could not be ascertained from the few shallow prospects existing.

The ore bodies are the result of the mineralization of certain layers in the zones of slates or schists. Quartzitic, micaceous, and calcareous beds all carry ore in greater or less amount. If the zone of slates is narrow—1 to 2 feet—the entire width may be more or less mineralized; in this case the walls are granite. In the wider belts the ore shows in considerable deposits in some of the layers, in others in much less amount; in others still it may be altogether wanting.

Evidences of fissures were slight, though in some instances the rocks were contorted to a considerable degree.

The ores are argentiferous galena, and antimonial and arsenical sulphides, also silver-bearing, probably. They are more or less altered near the surface. Their value varies greatly, but in the assorted ore it is sufficient to warrant shipping by pack train.

THE YELLOW JACKET DISTRICT.

This district lies southwest of Salmon City, on Yellow Jacket Creek, a tributary of Camas, which in turn enters the Middle Fork of Salmon River. It is in the midst of mountains of great ruggedness and is approached by trail from Challis and Salmon City, each about 60 miles distant. From the latter place, however, a good road has just been completed via Leesburg to the mouth of Fourth of July Creek, 12 miles from the mining camp. The outward communication from Salmon City is by wagon road 75 miles to Red Rock, on the Utah Northern Railroad; from Challis by wagon road 75 miles to Ketchum, the terminus of a branch of the Oregon Short Line. The altitudes above sea-level along the Salmon City road west are given below.

Altitudes between Salmon City and the Yellow Jacket district, Idaho.

	Feet.
Salmon City, about	4,000
Divide between the waters of the main Salmon and Big Creek	8,500
Leesburg	6,550
Big Creek at the mouth of Napias	5,500
Mouth of Fourth of July Canyon	5,900
Divide between the waters of Big Creek and Yellow Jacket Creek	7,800
Yellow Jacket Camp	5,875

The readings, which are from an aneroid, if out, are a little too high.

The Yellow Jacket camp is 10 to 15 miles below the head of the basin drained by Yellow Jacket Creek and its upper tributaries. The gorge of the main creek at the camp is about one-fourth of a mile wide, closing to 50 or 75 yards just above, with occasional narrow openings still higher. Below the camp the width of one-fourth to one-half of a mile is maintained for at least a mile or two, and along this portion are gold placers in preparation for being worked. The sides of the gorge are comparatively steep, and the country about is well timbered. Two or three gulches enter the Yellow Jacket at the camp, one from the south, the others from the north, the latter short, though reaching well toward the summit of the ridge. The two great lode properties are those of the Columbia Consolidated Gold Mining Company and the Yellow Jacket Mining Company. Other claims are located but undeveloped. The Columbia property is northwest of the main stream, in the divide between this and its tributary, Hoodoo Creek. The east side of this divide is that on which present exploitation is conducted. It presents a steep, slightly indented slope, advantageous for the opening of mines. The Yellow Jacket lode is between 1 and 2 miles northeast of the Columbia and also north of the main stream. It is located well up the slope of a steep hill, the southern terminal of a spur from a massive ridge in the curve of Yellow Jacket Creek. This property is separated from the Columbia by the two lateral gulches mentioned above. The mining region in its entirety extends to the east for a mile or two up Yellow Jacket Creek in the hills on either side, and to the

west about the heads of Hoodoo, Lake, and Wilson creeks. West of Wilson Creek is the divide separating it from the Middle Fork of the Salmon. South and southeast of the Yellow Jacket camp the ridge separating it from Camas Creek and its tributary, Silver Creek, is high and rugged, its topographic configuration being most irregular. The ridge is the site of great volcanic activity in past time.

Yellow Jacket Creek is a small stream, but the water is sufficient for milling and other purposes in connection with vein mining. For the placers it must be utilized chiefly in the early part of the season.

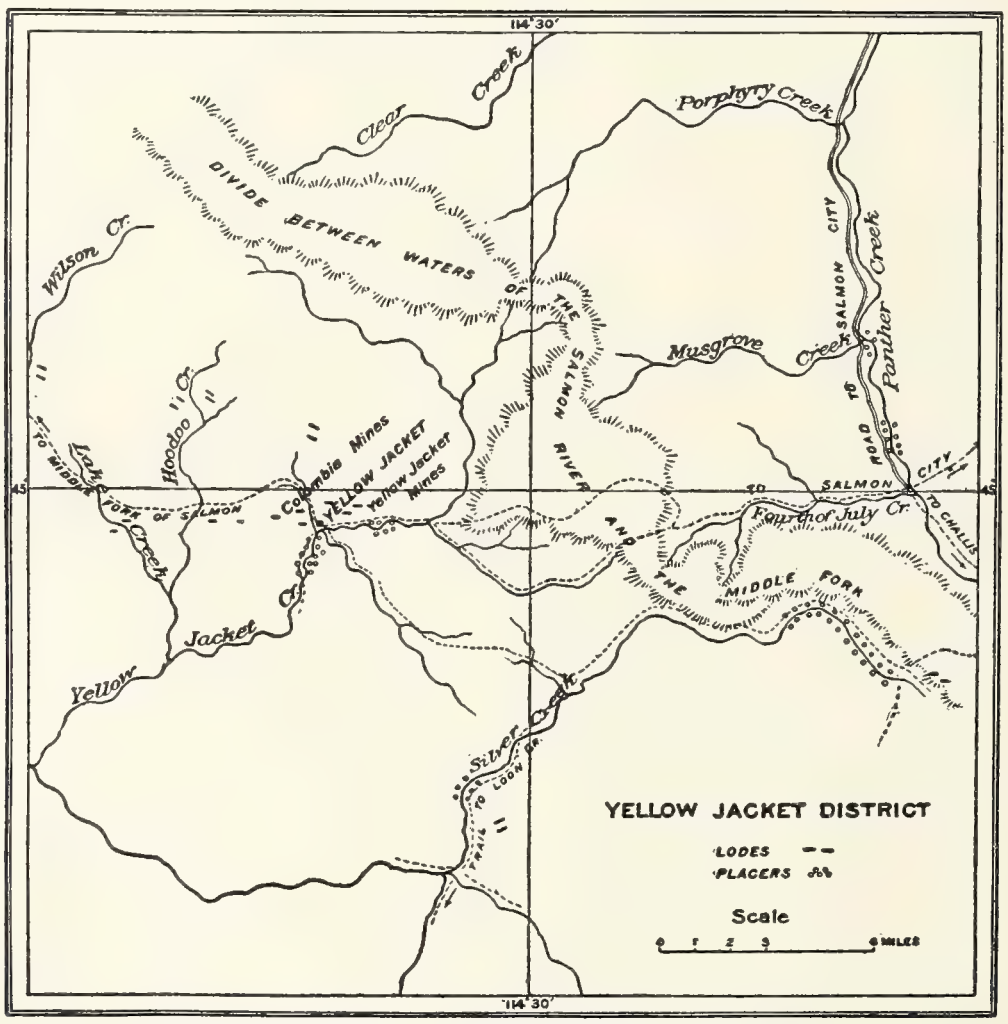


FIG. 40.—Sketch-map of Yellow Jacket district, by F. D. Howe.

The geology of the Yellow Jacket region was but generally examined in the reconnaissance. The district lies well within the area of crystalline schists, but local exposures of the gray granite so common in Idaho occur in the ranges about, some of them probably of considerable area. It is reported, for instance, in extended outcrop on the head of the main fork of Yellow Jacket Creek, 10 to 15 miles above the camp, in the divide between the waters of the Salmon and the Middle Fork. Abundant débris from this source shows along the creek bottom. It is also said to occur a few miles west of the district, along and beyond

the Middle Fork, a statement borne out by the appearance of the topography in that direction. The prevailing rocks, however, are the crystalline schists, quartzitic and micaceous chiefly, but with occasional bands more or less calcareous. The quartzitic variety predominates, and in one instance, in a layer of typical quartzite, distinct ripple-marks were observed on the stratification planes. The series is thin bedded throughout.

The eruptive rocks include rhyolite, trachyte, andesite, quartz-porphyry, mica-diorite, syenite, aphanitic syenite and minette (lamprophyre), and diabase. Of these the quartz-porphyries, rhyolites, and andesites occur in the heaviest and apparently most irregular bodies; the others, usually as narrower dikes. The quartz-porphyry, and the aphanitic syenite and minette (lamprophyres), called "syenite" by the miners, are most commonly associated with the metalliferous veins. The lamprophyres, according to the observations of Mr. F. D. Howe, manager of the Columbia Consolidated Gold Mining Company, when present and in contact with the veins, are usually their foot wall, while the hanging wall may consist of quartzite, quartz-porphyry, or some other one of the eruptives. The lamprophyre dikes are considered as indicative of the near presence of an ore body, so persistent is their occurrence in this connection; at least this is the case on the Columbia Hill. On the Yellow Jacket Hill the lamprophyres do not seem to occur so often nor in such intimate connection with the veins; indeed, the veins themselves differ in the two hills. The diabase was observed only on the Yellow Jacket Hill. The andesite occurred on the divide between the Fourth of July and Yellow Jacket drainage, while the rhyolites were most conspicuous 1 to 2 miles east of the camp and on Fourth of July Creek. Quartz-porphyries in heavy masses occurred both at a distance and on the crest of the ridge just above the Columbia mines. Occasionally a dike appears to be interbanded with the schists, but in most cases they cross the dips. The influence of the eruptives upon the mineralization of the region is undetermined.

The entire region between Panther and Camas creeks, which includes the Yellow Jacket mining district, has been in former times one of great dynamic disturbances; folds, flexures, and faults, in addition to the intrusion of the eruptives, occur. The structure is therefore difficult to determine, and the difficulty is increased by the similarity of the schists from the base to the summit, rendering identification of horizons impossible. In general the structure as suggested by strikes seems to have been developed on lines varying from N. 30° E. to N. 20° W., with local divergences to N. 60° E. and N. 60° W. This is evident both in the divide between Panther and Yellow Jacket creeks and the country to the west, to and beyond the Yellow Jacket mining camp. Moreover, it is on these lines that the majority of the eruptives have cut through, although there are doubtless instances in which the dikes cross the schists at greater or less angles with their strike. Again, in

some of the folds, on both small and large scale, slates and dikes together appear to have swerved from the normal or more usual trend.

The dips in the Panther-Yellow Jacket divide, along the route traveled, are nearly all steep. On the eastern side the beds more commonly incline to the east when departing from the vertical, and this direction becomes pronounced along Big Creek between Fourth of July and Napias, where dips as low as 20° are sometimes encountered, from 20° to 35° being quite common. On the western side of the divide a vertical position is maintained by much of the series, but in instances of departure from this a westerly dip is perhaps most usual, though a steep easterly inclination is occasionally met with. The westerly dip becomes more pronounced on approaching the vicinity of the Yellow Jacket camp, notwithstanding that in this immediate region the strata have been extensively fractured and crumpled, with consequent variation in both strike and dip. West of the Yellow Jacket camp the structure lines of the formations are unknown.

In general it appears from the foregoing observations that the high range forming the Panther-Yellow Jacket divide marks the axis of an anticline, and that on the west side, especially, the rocks have been locally fractured and bent, affording an opportunity for the locus of mineralization in the hills about the Yellow Jacket camp.

In the Columbia Hill the schists are particularly crumpled and fractured. There are several lines of structure, all bearing upon the geology of the ore bodies. Three, N. 20° W., N. 15° E., and N. 30° E., are strikes of the schists, representing flexures in their trend. Occasionally these are also the courses of joint planes. Two other lines of structure, N. 60° E. and N. 15° to 25° W., prevail throughout the region, the directions of joint planes and perhaps also of strikes of the schists. These directions for the joint planes become especially significant when it is known that they are also the directions of the two chief systems of ore deposits of this hill, the veins of a N. 60° E. trend forming the principal system. The observed dips of the locality were all to the west, varying from 10° to 60° and even 90°.

In the Yellow Jacket Hill, a mile or two northeast of the Columbia, the strike of the schists is N. 50° to 60° E., and this is here the strike of the main vein of the property also. Schists and vein together have an average dip of 33° W., locally increasing to 45°, 50°, or even 70° or 90°, but the steepest dips are rare. Faults doubtless occur in both the Columbia and Yellow Jacket hills, but their relations to the ore bodies, eruptives, and country rock, in strike and dip, were not determined.

The principal system of metalliferous veins in the Columbia Hill—that having the N. 60° E. trend—appears to be a series of mineralized zones of highly fractured material, in width from a few feet up to possibly 75 or 100; 50 was the maximum observed by the writer. Their dip varies between 30° and 70° W. The foot walls are frequently

aphanitic syenite or minette (lamprophyre; local term, "syenite"), while the hanging wall may be either quartzite, quartz-porphyry, or some other eruptive, occasionally even the syenitic rock. The eruptives in general parallel the veins in strike, and, in some instances at least, the quartzites also seem to do so.

The fractured zones are clearly defined, but it was not possible in the time available for the examination to determine satisfactorily whether they were at all points parallel with the line of strike of the schists or in part independent of and divergent from this. Again, it was equally impossible to determine in the yet comparatively shallow openings whether the zones, when coincident with the schists in strike, dipped with them or at a greater or less angle. Whichever may be the case, it will not alter the character of the deposit. The vein material is a breccia of fractured schist, in one or two instances including pieces of the accompanying lamprophyre ("syenite"). The breccia is bound together with siliceous matter (quartz), and the filling completed with the mineralization of the zone. From the included lamprophyre it would seem that at least the fissures it filled existed prior to the fracturing which resulted in the brecciated, mineralized zones. In regard to the other eruptives, the time relations are obscure.

The metallic contents of the fractured zones are carried not only in the interstitial quartz but often in the fragments of the schists and slates themselves, impregnation of these having taken place to considerable depths, though perhaps not to the complete replacement of the central portion. The exterior of such fragments under atmospheric or other oxidizing agencies often appears rusty, from the partial alteration of the sulphides to oxides or carbonates. The deposition of the metallic contents has been more or less unequal throughout the lodes.

The system of veins on the Columbia property having a N. 15° to 25° W. trend is less prospected than that just described. Such veins have in a few instances been observed coming into one or another of those of the N. 60° E. system, but their extent in the line of their trend is undetermined. Neither could it be observed at the time of the examination whether at all points these were confined to the areas in which a N. 15° to 25° W. strike prevailed for the schists; whether, in fact, they did not, as suggested in one or two instances, form lateral "feeders" to or offshoots from the N. 60° E. system, on the stratification or other planes, or even as fissures. It is significant that joint planes having a direction of N. 25° W. are of frequent occurrence throughout the property of the Columbia Company.

The ores of the Columbia mines are chiefly copper sulphides carrying gold and silver and ranging in value up to $150 per ton, with concentrates increasing in richness according to the completeness of the operation. An average ore is stated to be about $30, while $40 to $50 is not infrequent. The sulphides near the surface are more or less oxidized, or altered to carbonates, affording a free milling ore; and it

is stated that there is more or less free gold in the unaltered portions also.

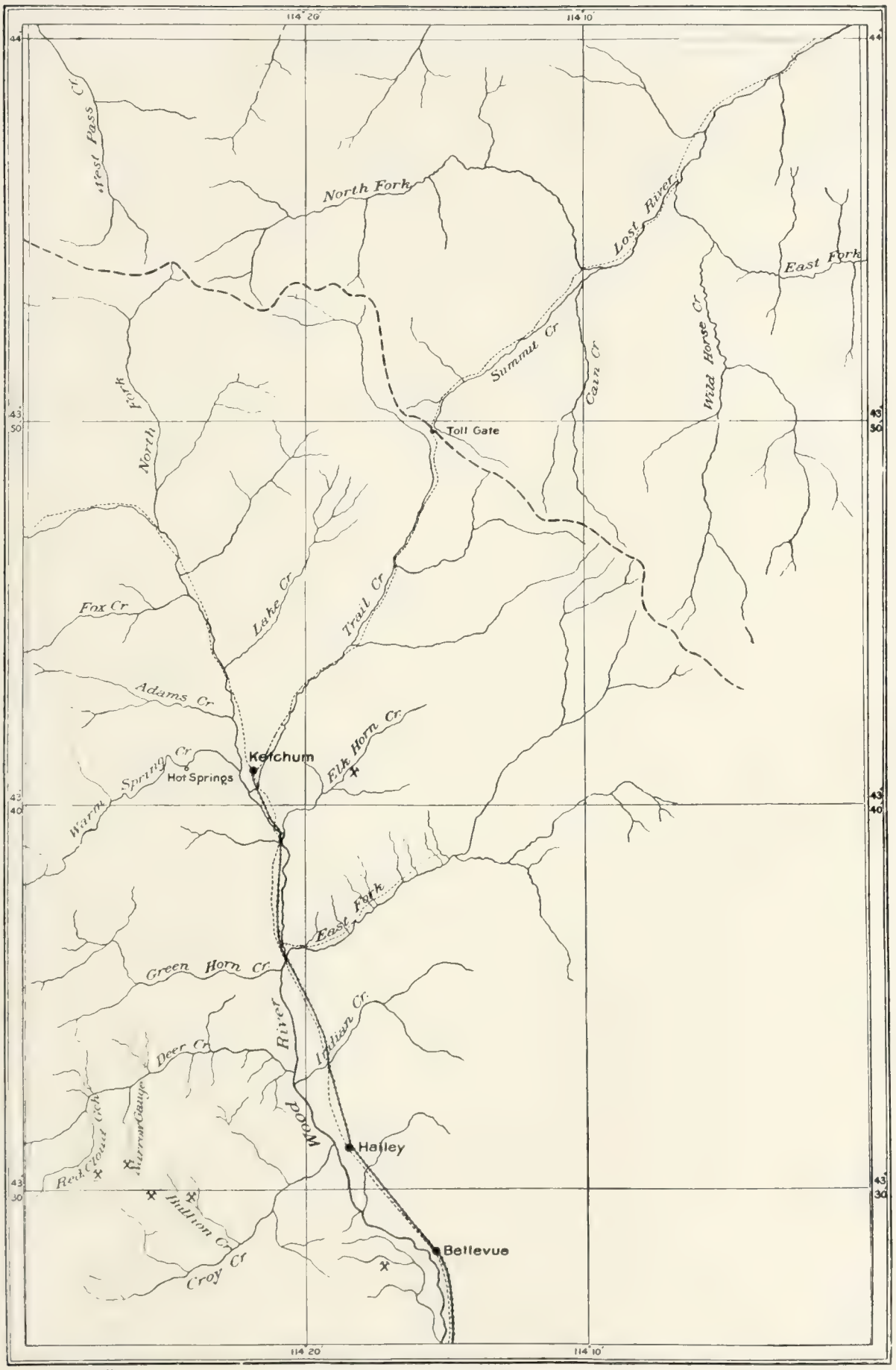
In the hill embracing the property of the Yellow Jacket Gold Mining Company there appears to be, so far as shown by the present state of exploitation, but a single vein, or at most two, if we except a number of small stringers in their vicinity. The country is a quartzitic schist in layers of varying thickness and hardness. The veins are of quartz, and lie with the schists, striking N. 60° E., and dipping northwest on an average 33°, increasing at points to 45°, 60°, or even 90°. But a single instance of a breccia was observed in the superficial examination given the mine; this consisted of included fragments of country rock in a calcite cement. The highly brecciated condition prevailing in the Columbia mines appears to be absent in the Yellow Jacket. The vein has been traced but a short distance beyond the Yellow Jacket Hill. The thickness of the vein is said to reach 40 feet locally, but the maximum seen by the writer was about 15 feet. The quartz is said to occur in lenticular bodies of varying dimensions. Occasionally eruptive dikes appear in the mine, chiefly of aphanitic syenite or "minette" (lamprophyre) and diabase. Their relations to the ore bodies were not studied.

The ore of the Yellow Jacket mine, or at least of that portion of it visited by the writer, is a free-milling, auriferous quartz, with one or two small local bodies of hematite and an occasional but rare copper stain. This difference from the ore of the Columbia mine is as marked as the difference in the manner of occurrence and character of the veins themselves. The mass of the ore of the Yellow Jacket mine is said to run from $7 to $30 per ton, with local values much higher. An ore of common occurrence is one of $18 or $19.

The formation about the summit of the Yellow Jacket Hill has undergone considerable disintegration, and the surface is covered with débris which is reported as carrying free gold from a trace up to $7 per ton. This may be milled at a profit.

THE WOOD RIVER DISTRICT.

This district embraces an area 15 to 25 miles square on upper Wood River and adjoining streams, just within the southern edge of the mountain mass of Idaho. The greater portion of the district lies within the confines of the Wood River drainage. This has formed a topographic depression ridged with spurs of the inclosing ranges, the intervening gulches being sharply eroded to depths of 1,500 to 3,000 feet. The central valley, one-fourth to one-half mile wide, ranges in altitude from 5,000 feet at its lower end (Bellevue) to 6,000 feet a little above Ketchum, rising still more rapidly beyond. The periphery has an elevation of 9,000 to 10,000 feet, a single peak, Mount Hyndman, 15 to 20 miles southeast of Ketchum, reaching 12,000 feet, the highest in the State.



SKETCH MAP OF WOOD RIVER DISTRICT.

The ranges and their spurs are somewhat rugged, and their configuration varies according as the rocks entering into their composition are quartzites, limestones, or shales. Most of the streams are comparatively small, but Wood River has a large volume of water. The bottom lands along the main stream are cultivated and supply the mining camps; the hills are timbered in varying amount, though the mines are not always in close proximity to the heavier bodies. Hailey and Ketchum, 12 miles apart, are the important towns of the district, and are connected by a branch with the Oregon Short Line at Shoshone.

A résumé of the general geology for the district shows a base of gray granite; resting upon this, in one locality, dark and light colored quartzites with calcareous beds; in another, a heavy mass of pink quartzite, varying in thickness up to 500 feet; and in a third, a great series of black or dark-gray calcareous shales. Intercalated somewhere in this series, probably between the gray shales last mentioned and the dark quartzitic series, are from 300 to 500 feet of heavy-bedded limestone, resembling somewhat the sub-Carboniferous of the Rocky Mountains. The arrangement suggested as most probable, in the light of the evidence at hand, is granite, heavy pink quartzite (Cambrian), dark and light quartzitic series (at least post-Cambrian), the limestone resembling the sub-Carboniferous, and the gray calcareous shales (Carboniferous). All these are cut by eruptives—hornblende-andesite and hornblende-mica-andesite. The upper, calcareous, shaly division carries most of the mines of the Wood River district proper, but in the outlying portions the dark quartzite series and the granite also contain mineral deposits of one kind or another.

Throughout the Wood River region proper there is a general N. 25° to 40° W. strike with a southwest dip, usually between 30° and 60°; but local variations occur, sometimes involving a region of considerable importance. The southwest dip is that of the half of a probable anticline, the eastern half being in the Lost River country, and the axis along the divide between this and Wood River.

Faults are of frequent occurrence throughout the region. They are of many directions and of varied inclination and throw. The amount of throw is often obscured by the similarity of the strata on either side of the fracture plane and by the great thickness of the series opposed. Following are the types observed, which are probably representative for the region.

One, the plane of which is horizontal, displacing a dipping ore body 50 feet or more: the upper part of the vein is carried in the direction of the dip, both ends of it being broken over, with a dragging of the ore along the plane of the fault. Faults inclined 25° to 50° also occur, their strikes often divergent; such faults are known to have drained the upper levels of a mine when struck at a lower. These faults may sometimes be traced at the surface by a break in the topography, a line of gentle depression or otherwise. It is often significantly remarked

by the miners of various districts that the ore follows the line of a gulch. The position of a gulch is often determined by a fracture-line, and it is along a fracture-plane that mineral solutions have found their way; hence the coincidence. Fracturing has also taken place with a minimum of displacement, at times no more than a crushing of a particular zone with a slight slipping of fragments upon one another or upon the walls. This was observed both coincident with the stratification and across it. Slickensides are observed nearly everywhere that there has been movement between the rocks on the two sides of the faults, the grooves lying in many directions. In addition to the above recognized faults there are many points along Wood River and its tributaries where the series of calcareous shales opposes the underlying heavy-bedded gray limestone, which is indicative of considerable throws. The faults of the Wood River region are among the most important features requiring examination. Flexures also occur, but study of their details was not attempted.

Mineralization of the veins in the Wood River district has apparently taken place in a manner wholly independent of the eruptives. The region has at different periods been one of great fracturing, on both a large and a small scale, and passages have thus been afforded, in some instances for the intrusion of dikes and other irregular bodies of eruptives, in others for the flow of mineral-bearing solutions. These solutions have not only filled the fractured zones themselves but have oftentimes found their way into the more solid beds of limestone adjoining, replacing them to such a degree that they too became of economic value.

The mines of the Wood River region that have thus far been most productive lie within the periphery of the drainage basin itself. A single exception, perhaps, is the Camas No. 2, near Doniphan, just beyond the southwestern border. The position of the mines may be isolated, or there may be certain localities where the deposition of ores has been especially active, possibly through an easier access afforded the mineral-bearing solutions. For lack of time it was impossible to do more than (under the guidance of two or three of the mining men acquainted with the district) to visit a few localities which together would afford a general idea of the occurrence of the ores and of their character.

On both sides of Wood River, fracturing, faulting, and folding were suggested in the distribution of the strata and their many variations in strike and dip. For the region east of the main valley the general anticlinal structure described for the southeastern portion of the Sawtooth Range prevails. The strike most common is N. 25° to 40° W., the dip usually southwest. Faults of greater or less extent and magnitude may be seen both in the mines and upon the surface, and folds were discerned from a distance by the writer. The area of examination, however, was very small. On the west side, the region about the head

of Deer Creek and its tributaries, extending over to Bullion Creek and the gulches west, received most attention. It is 9 to 10 miles west of Hailey, and 2,000 to 2,500 feet higher. The geology along lower Deer Creek is obscure and subject to sharp changes in both structure and stratigraphy. South of the creek limestones bearing a close resemblance to the heavy-bedded gray variety of the district appear in the bluffs in one or more flexures, while eruptives form a portion at least of the higher hills beyond. On the north, for the first mile, an eruptive closely resembling the hornblende-andesite higher up Wood River occupies the interval opposite the flexed limestones on the south. The eruptive finally gives way to the dark quartzitic series; this in a mile or two to a heavy-bedded blue limestone, which also now appears on the south side of the valley. In about 200 yards the limestone is succeeded by the black and gray calcareous shales, here more calcareous than at many points in the district. The general strike of this series is across the creek, the dip probably upstream, or west.

At the Warm Springs, which are about 4 miles above the mouth of Deer Creek, the slates are succeeded by gray granite; it is impossible to state whether in natural sequence or by faulting, but the latter is suspected. The granite extends for 3½ miles along the creek, the foliation planes having the general strike of the country, N. 25° W., and dipping upstream, westward. The granite is overlain by 500 feet of white quartzite, which, however, disappears within a mile or two south of the creek, the manner of disappearance not being determined. This is overlain by the black and gray calcareous shales and limestones, the ore-bearing series of the Wood River region, which, where the quartzite has disappeared, at the head of Narrow Gauge and Bullion gulches, come directly down on the granite. The dip of the entire section, from granite up, is westward until at the head of Deer Creek and of its tributary gulch, Red Cloud, it gradually changes to the southwest and south, the strike of the slates changing accordingly. This departure in the strike and dip is particularly conspicuous in the high ridge separating Red Cloud Gulch from the gulches to the south in which the Red Elephant and Bullion group of mines are located. For all this, however, it is a local feature, and the normal strike of N. 25° W. prevails over much of the area included within this southwestern corner of the Wood River district.

The hill in which the Red Cloud, Red Elephant, Bullion, and French groups of mines are opened is one of marked fracturing as well as folding, both on a large and small scale. The fractures occur at angles divergent with the strikes and dips, and also along their planes, and are locally so complex as completely to obscure the bedding. No clearly defined system of fracturing has thus far been worked out for the hill, but that most prominent has a N. 25° W. direction. This also carries several of the more important mines. The greatest irregularity appears to be in the northern face of the hill. In the southern, or at least in

the spurs on this side, the strata seems to have regained the strike normal for the district in general, N. 25° W., the dip being uniformly westward, 30° to 60°, or locally even nearer the vertical. The precise connection between the structure of the northern and southern faces of the hill was not determined.

The hill just described is on the very edge of the great mountain mass of Idaho, but few foothills intervening between it and the lava plains of the Camas and Snake valleys. Neither the region at the very head of Deer Creek and its tributary, Red Cloud Gulch, nor the country to the west of this was visited. It is said that granite lies beyond the Wood River drainage, in this direction, and the observations of the writer from a distant point to the south confirm this in part. It is quite possible that such succession of granites west of the Deer Creek shales and slates is brought about by a bending up of the strata to the west, making a syncline somewhere between the Deer Creek mines and the granite. Faulting is the alternative.

The ore deposits of the Wood River region, so far as observed by the writer, are of three classes: those occupying fractured zones in the great body of calcareous shales and limestone; those occurring in beds of limestone; and typical fissure veins. There are instances, however, in which these classes seem to occur in connection one with another.

The fractured zones are more or less prominent throughout the district. Such zones have the appearance of a breccia of the country rock, with the interstices filled with quartz, not infrequently supplemented by calcite in minor amounts, the whole more or less impregnated with the metallic contents. The width of such zones varies from a foot or two up to 15 or 20 feet, and may be even greater locally. The zones may coincide with a particular bed of limestone or may cut across both strike and dip at various angles of divergence. When this divergence is slight it is difficult to distinguish between an ore-bearing bed and an independent zone of fracture, except through the breccia structure. What are called foot and hanging walls are also recognized in veins of this kind. Where the fractured zone crosses the strata, occasionally a lateral ore-shoot follows a bedding plane for a short distance, given off from the main channel of mineralization; indeed, mineralization along bedding planes, however slight, is considered an indication of the near approach to a vein.

The fractured zones may have resulted from simple crushing with a minimum of movement; or, as is apparently often the case, the movement may have been considerable. The creation of the spaces now occupied by interstitial filling may have been by actual separation of the fragments; or they may have been merely a network of joints and cross-joints along which solvents easily passed, carrying away portions of the lime and so creating interstices which were subsequently filled with the mineralizing solutions; or, perhaps, even the calcareous material of the breccia itself was gradually replaced by the metallic

compounds. When considerable movement took place in the zone of fracture, fissures were often created within the boundaries of the zone, the deposits filling them assuming the character of local fissure veins. It is possible that in such cases the fissuring may have been wholly secondary to the primary fracturing—cracks opening within the already partly mineralized body of rock. In other cases the original movement may have resulted in a fissure, the present brecciation being due to included fragments of the country rock, themselves, perhaps, minutely fractured.

In the mineralization of the fractured, ore-bearing zones, the metallic sulphides occur distributed through the interstitial filling, or accumulated in thin layers along partings in the vein material, or, again, in massive bodies of ore, 1 to 20 feet thick, on one or the other of the walls, in the interior of the zone, or occupying its entire width. Many instances of the replacement of limestone within the fractured zone by metallic compounds occur. Such might also have been the case with the heavier bodies of ore. On the other hand, the heavier bodies may have been deposited from solution in the fissures opened in the fractured zone. Oftentimes, where there is a vein of nearly solid ore, or at least a body of highly mineralized rock in a fractured zone, the portions of the zone on either side, if the body is in the interior, may also be mineralized in paying amount and the adjacent country itself may carry a small percentage of ore.

Of the class of ore deposits occurring in beds of limestone a single instance was observed by the writer, but this form of deposit may not be uncommon in the Wood River district, where like conditions are maintained over such an extended area. The deposit bore considerable resemblance to the deposits at Leadville, in the "blue limestone" of sub-Carboniferous age. It was not, however, accompanied by eruptives, and this absence of eruptives in connection with ore bodies prevails in the Wood River region; the source of the mineralization is therefore quite different in the two localities. In the deposit observed by the writer there is a mineralized zone of limestone with an included vein of ore. Where seen the total width of the metalliferous zone was 5 or 6 feet, and that of the included vein 3 inches to 1½ feet. Both are said to have reached greater width in other portions of the mine, 12 feet of galena being reported at one point. The country rock is the dark-gray calcareous shale and limestone, the gangue, quartz with a little calcite, and here and there portions of shale. The ore bodies in veins of this nature are said to be nearly independent of one another, and appear to have originated in the mineralization of larger or smaller portions of limestone which were within easiest access of the mineral-bearing solutions. It is quite reasonable to suppose that in a region of this kind in the folding which the strata have undergone bodies of limestone, parts of an entire bed, may have been reticulated with cracks without displacement of the fragments, and that through such bodies solutions

found an easy passage. In a region of such fracturing and so many channels for the flow of mineral solutions, any of the limestones may become locally ore-bearing. For the preference of the limestones of the shaly series over the massive gray limestone of the region, no explanation was arrived at; the suggestion occurs that it may be due to original composition.

The class of veins which may be considered as having had their origin in fissures—fissure veins—occurs both in the great calcareous slate and limestone series of the Wood River district and in the granite just beyond. In the slates they are doubtless numerous. They are here distinguished by their strike and dip, which is at variance with that of the slaty beds, by slickensides, by selvages of clay, by occasional included fragments of the country, and by the character of the filling, which is a heavy deposit of quartz in one or more layers, with or without accessory minerals like calcite, the metallic contents being deposited in masses along the planes or disseminated throughout the ledge matter. Moreover, as the vein crosses the stratification of a series of thin-bedded rocks, the nature of the country is constantly changing, both on the course of the vein and in depth. Original fissure veins in slates contain more or less débris from the country, but are usually easily distinguished from the zones of fracture and their included local fissures.

Near Doniphan, on the head of the east fork of Camp Creek, southwest of the great area of calcareous slates, and in the region of granite, is a prominent quartz ledge having a general course of N. 30° to 35° W. and extending with interruptions for 3 or 4 miles across the country, Doniphan being near its southeastern terminus. The granite is somewhat foliated, and, so far as observed, the planes have a prevailing strike N. 25° W. and a dip southwest. The ledge presents some minor curvatures of strike, and the dip also varies a little from point to point, but is in general about 45° NE. The vein doubtless belongs to the class of true fissures—a view strengthened by slickensides, clay selvages, and fragments of the country in the ledge matter. There are several locations upon the ledge, but the Camas No. 2, at the southeastern end, is the only mine of present importance and is said to have been a good producer in earlier times. The stopes would confirm this. It is now about being reopened. The width of the ledge varies, the maximum observed being between 6 and 10 feet. The quartz is banded, coarsely crystalline and showing little mineral, or fine-grained and mineralized to considerable amount. At a single point a bit of limestone resembling that of the shaly series was discovered adjacent to the ledge, but its presence was inexplicable. Its appearance, however, was that of an intimate part of the rock, not an included fragment. The ore occurs in shoots of greater or less size, the mineral contents being either disseminated in particles throughout the entire width of the ledge, concentrated in bunches on the walls or in the interior, or confined to certain benches.

The ores of the Wood River district are lead-silver and gold. The former is practically confined to the great series of calcareous shales, the latter to the granite.

Associated with the galena of the first class of ores are blende, pyrite, arsenical pyrites, gray copper, erubescite, and occasionally native silver. Blende and common pyrite are the most widely occurring and abundant associates; the others are comparatively rare. Carbonates usually occur near the surface. The galena is fine to coarsely crystalline, and occurs disseminated, bunched, or in extended bodies. It often shows striation resulting from twinning. The blende occurs either through the galena or in distinct portions of the vein with but slight admixture of galena. The pyrite may occur in the same manner as the blende, but is of wider and more universal distribution than any of the other minerals, and moreover is frequently found in the country adjacent to the ore bodies. No examination as to the contents of the ores was attempted, but they are said to run as high as 160 ounces of silver and 70 per cent of lead to the ton, with an average considerably below this.

The gold ores occur in the veins in granite. They are in part free-milling, in part smelting. The minerals associated with the gold are pyrite and chalcopyrite, with their alteration products, and a very small amount of galena, probably argentiferous, as silver is found in such ores on examination. The milling ores are said to run from $8 to $15 per ton in free gold, the assays indicating a value of $26 in this metal.

THE SILVER CITY DISTRICT.

This is located on the southwestern slope of the Owyhee Range, about the head waters of the Jordan River, a tributary of the Owyhee; the district extends, however, to the heads of other streams in the vicinity, and altogether occupies an area 8 or 10 miles square. The two leading towns are Silver City, at the head of Jordan Creek, and De Lamar, 7 miles below, to the west. The Jordan Valley and its tributaries are sharply eroded to depths of 2,000 to 3,000 feet below the crests of the range and its spurs. The water supply is light. Timber is scarce. The district is 50 miles from the railroad, Nampa on the Oregon Short Line being its station. An excellent wagon road over the mountain and across the Snake Valley connects the two points.

The Owyhee Range, in which are situated the two important mining camps of Silver City and De Lamar, is primarily a granite range, in later times cut by rhyolite, diabase, and basalt.

The two leading mines of the district are the De Lamar at De Lamar, and the Black Jack, 1½ miles west of Silver City. Both are on clearly defined fissure veins in rhyolite. There is, however, in the Black Jack an associated rock, diabase, and on the mountain side below this mine basalt occurs. The rhyolites are several miles in extent, but whether the two mines are on the same body was not ascertained. The rhyolite in a decomposed state is sometimes mistaken for granite by the miners. The diabase, which is called "trachyte" by the miners, occurs locally

on one side of the vein in the Black Jack mine, and in the Trade Dollar, to the east of the Black Jack, it is said to form both walls. This rock is younger than the rhyolite with which it is associated.

The veins trend between N. 10° and 60° W., varying locally; the prevailing dip, which is steep, is west or south. Fracture planes cross the veins at greater or less angles, but examination was not in sufficient detail to determine a system. The width of the veins is from an inch or two up to 10 feet or more. The vein matter is quartz, banded or massive, coarsely or finely crystallized. The quartz locally shows a brecciated structure, coarse or fine, indicating movements since the formation of the veins; the fragments are often somewhat abraded and surrounded by a clay gouge. Not infrequently, also, included

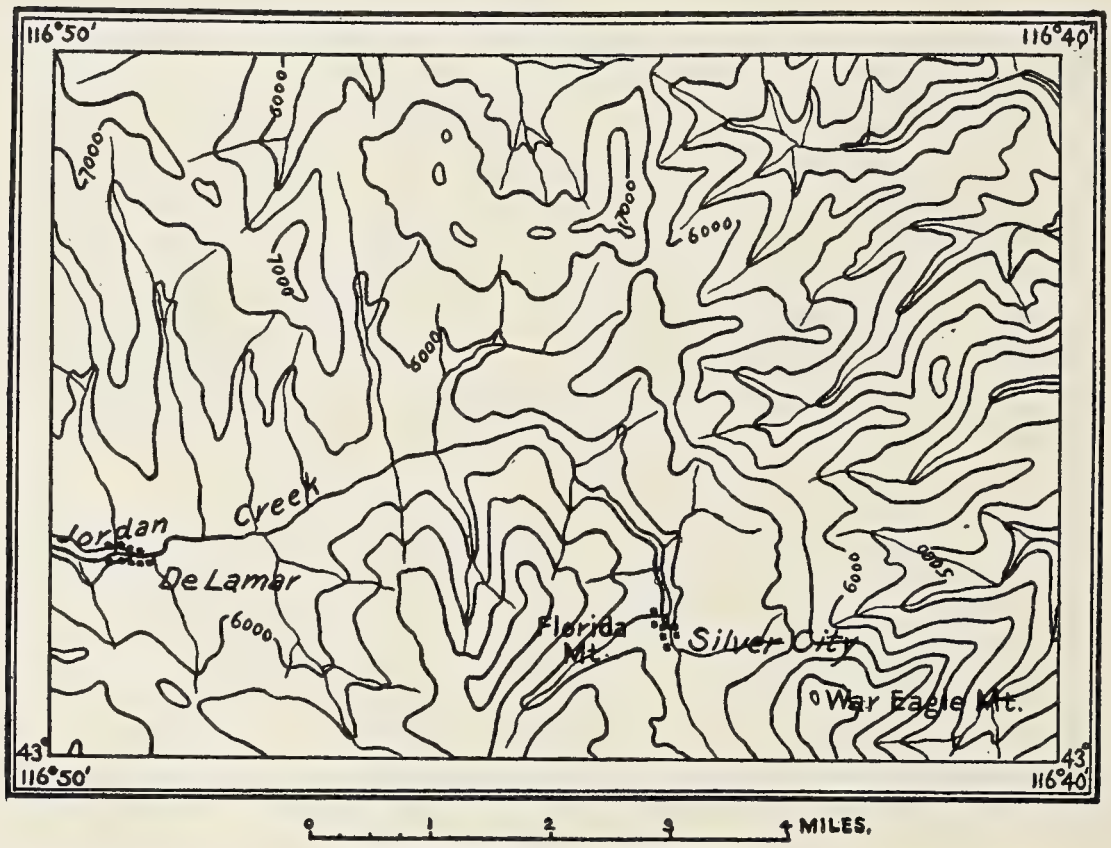


FIG. 41.—Sketch-map of Silver City.

fragments of the country rock are found, either as horses or in small, angular pieces. Talc, so called, is of common occurrence in certain localities in the mines, even in the interior of the ledge. Besides this, there is the usual selvage on the walls, attaining locally a considerable thickness.

The ores are gold and silver. Both metals occur native, but the silver is found in large proportion as argentite. The chloride is also present. Pyrite, auriferous and nonauriferous, occurs. The talc in the veins is a remarkably productive class of ore, carrying a large amount of argentite. The ores are generally of very high grade.

PLACERS.

The mills of the companies are well equipped and are kept running night and day a greater part of the year.

The placers on the route of reconnaissance are chiefly gravel bars along stream bottoms. From reports some of them have yielded fabulously in the past, but at present work is prosecuted only by a few scattered Chinese laborers. The placer gravels encountered were all on streams that had their sources in the gray granite or in the crystalline schists which lie upon this. Indeed there are apparently but few streams rising in these terranes that do not at some point carry pay gravel or have not already produced more or less gold. Among the more notable instances are the bars of the main Boise and its tributaries—South Fork below Rocky Bar, and Middle Fork, below Atlanta; Loon Creek, entering the Middle Fork of the Salmon; and Yellow Jacket Creek below the mining camp. Leesburg, on Napias Creek, has been the center of a great placer district in early days, and at California Bar, 3 miles below, a company is now preparing to work a supposed extensive placer.

Different from the foregoing class of placers is that on Kirtley Creek, 8 miles east of Salmon City, within 2 miles of the base of the Continental Divide. There is here, indeed, as along several of the streams heading in this range, the usual river and creek gravel bars, carrying a greater or less amount of gold, but in the bluffs of the creek there is also an extensive placer probably of Tertiary age, which is now being opened. The general feature of this deposit is, briefly, a succession of Tertiary gravels and sands, which possibly correspond with beds farther out in the Salmon Valley that from paleobotanic evidence are Eocene or Miocene. The material was derived from the neighboring range, and formed a shore deposit of the intermontane lake. Their north-and-south extent was not learned, but it may be several miles. The gravels may not everywhere be auriferous, however.

The deposit as exposed consists, from base up, first, of a series of conglomerates and sandstones, about equally divided, cut to a depth of 15 feet, and found to be auriferous—in paying amount, it is said, under a sufficient supply of water. Upon this series is a very white, thin-bedded sandstone but a few feet in thickness, succeeded by two other layers, of white and yellow sandstones, 5 and 3 feet thick respectively, which are leaf-bearing; these are called by the miners bed-rock, as they form the foundation for the overlying gravels, which are unconformable and said to be fairly rich, especially near the bottom. The overlying gravels are fully 20 feet thick when present in their entirety, and are in turn succeeded by 30 feet of interbedded sandstone and conglomerate, the sandstones predominating, and all carrying more or less gold. This completes the succession of beds of supposed Tertiary age. The entire series, both above and below the line of non-

conformity, is flexed, a westerly dip of 15° to 45° prevailing. This bending of the strata indicates that if the portion above the break is not of the same age as that below, it is at least earlier than Pleistocene.

Resting upon any of the foregoing beds, according to their exposure in the past, is a Recent gravel, derived in part from that below, in part, perhaps, from the present mountain slopes. This gravel is said to be the richest of all, the result of a natural concentration of the earlier auriferous gravels. The gravel, both Tertiary and Recent, is of quartzite or quartzite-schist débris; the Tertiary portion is usually tightly cemented and somewhat difficult to hydraulic. The gold contents were not ascertained, but elaborate preparations are being made for mining.

The present supply of water is from storage reservoirs in the mountains, and is insufficient for constant work. It is proposed to take water from the Lemhi River, which would probably obviate this inconvenience.

COAL.

Two coal areas were encountered on the reconnaissance, one about Salmon City, the other at Horseshoe Bend on the Payette, 28 miles north of Boise. Both areas are probably Tertiary—Eocene or Miocene—confirmatory plant remains having been found in the beds at Salmon City and the series on the Payette bearing a close general resemblance to these in composition, in manner of occurrence, and in folding. The coal occurs in small seams in sandstones, shale or conglomerate lying within a few feet.

SALMON CITY VALLEY.

The only opening in this valley is a drift 20 feet in length in the east bluff of the Salmon River a mile below the city. There are here several thin streaks of lignite—the thickest, 6 inches—in 5 feet of carbonaceous slate and sandstone. The lignite has a dead-brown appearance, and its woody structure is plainly visible; the ash is high, as are probably also the water contents. It is valueless so far as exposed. The measures which carry this lignite underlie a large portion of the valley about Salmon City, and at several points show thin beds of carbonaceous shale, indicating the former presence of plant life and a tendency to the formation of coal; but the conditions seem not to have been those requisite for the development of a coal of economic value.

HORSESHOE BEND, VALLEY OF THE PAYETTE.

The valley of the Payette at Horseshoe Bend has a northeast trend, is about 9 miles long by 3 across, and is divided midway its length by the axis of an anticlinal arch having a general northwest direction. Coal occurs in both the northern and southern halves of the valley. The northern prospects were not visited, being reported but slightly opened and in unsatisfactory condition for examination. The only southern

opening at present is a surface cut and short tunnel on what is known as the Rob vein, of which the following is said to be a section, though only the upper coal was visible at the time of visit:

Section of the Rob coal vein, Horsehoe Bend, valley of the Payette.

Sandstone and shale	roof.
Coal	1 ft. 6 in.
Slate	1 ft. 0 in.
Coal	0 ft. 10 in.
Slate	1 ft. 0 in.
Coal	0 ft. 10 in.
Clay	floor.

The strike of the vein at the exposure is northwest; the dip, SW. 5° to 10°. A short distance south an eruptive a few hundred feet wide cuts the coal. Beyond this the measures again appear, but are of limited extent, owing to the proximity of the granite of the Boise Range, or of a second eruptive. Northwest the coal bed may extend for a considerable distance before reaching the edge of the valley, the western wall of which is granite.

The coal is black and comparatively hard. Following is the analysis of a sample taken from a small pile on the dump, which is said to have come from a tunnel inaccessible at the time of visit.

Analysis of coal from Horseshoe Bend, valley of the Payette.

Moisture	4.84
Volatile matter	36.23
Fixed carbon	54.55
Ash	4.38
Total	[1] 100.00

The excellent quality of the coal in the present instance may be explained by its proximity to an eruptive. It is questionable whether this grade would be maintained over the entire valley.

AGRICULTURE.

In crossing and recrossing the State the following facts in regard to agricultural possibilities were impressed upon the writer: Much of Idaho is a rugged mass of mountains, and but little area is available for farming in comparison with that of many other Western States. The intermontane valleys are few, but are very fertile and well adapted to hay, grain, vegetables, and fruits. Berries, apples, peaches, plums, and prunes, all, in one locality or another, attain remarkable perfection. In the Boise Valley and the country adjacent the prune, plum, and peach industries have been successfully started and promise enormous advances in the next few years. The apple industry is also large, but in this there is apparently a choice of location. In certain portions of the State a worm seriously deteriorates the crop. In the Salmon City

[1] No coke.

Valley, however, it has not yet made its appearance, and the apples grown here, upon the talus slopes at the foot of the mountains, and in the higher valleys, are the finest in flavor and the largest in size the writer has ever seen. Berries and vegetables may be grown with great ease in all the valleys of the State. The area for large farming operations, the growing of hay, grain, etc., is at present small, but is capable of great increase by the irrigation of the many thousand acres that can be selected on the plains of the Snake River. That such lands are suitable for cultivation under irrigation has already been proved by the successful farms and orchards now in operation. Such irrigation, however, can be accomplished only on a large scale, by heavy outlays of capital. Artesian water is possible at many points, the porosity of the strata, both in the Snake Valley and in the intermontane depressions, rendering a large subterranean circulation quite probable. Hot springs abound, remarkable for their number, distribution, and size. They are already utilized at Boise in the municipal economy.

THE GEOLOGY OF THE ROAD-BUILDING STONES OF MASSACHUSETTS, WITH SOME CONSIDERATION OF SIMILAR MATERIALS FROM OTHER PARTS OF THE UNITED STATES.

BY

NATHANIEL SOUTHGATE SHALER.

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THE GEOLOGY OF THE ROAD-BUILDING STONES OF MASSACHUSETTS, WITH SOME CONSIDERATION OF SIMILAR MATERIALS FROM OTHER PARTS OF THE UNITED STATES.

By N. S. Shaler.

INTRODUCTION.

The Annual Report of the Director of the United States Geological Survey for the fiscal year 1893–94 contains a memoir by the writer concerning the geology of the highways and the highway materials of this country.[1] The object of this memoir was to present in a general way the conditions of surface and understructure so far as they affect the building and maintenance of good carriage roads. In the following report an effort is made to show the nature of the work which may be carried on, with the end in view of securing such geological information as may be serviceable to the highway boards of Massachusetts.

It is well to state to the reader the conditions under which this report has been prepared; they are as follows: The Commonwealth of Massachusetts began, in the summer of 1894, the construction of a system of main roads which are to be built and maintained at the cost of the public. The experience of the first year of this work, the results of which have been carefully tabulated, makes it plain that true economy requires a systematic exploration of each proposed route with reference to the value of the road-building materials that may be obtained near by the way. As the amount of stone used in macadamizing a road a mile in length, having a width of 15 feet, is not far from 3,000 tons, the cost of the transportation of material for any considerable distance is necessarily a large part of the expense which is incurred in the constructive work. In many cases the proportion of this cost has amounted to more than 40 per cent of the whole expenditure. It is therefore plainly of first importance to take careful account of the stone which may be had near the roadside. Even where the rock is from its nature unfit for use in forming the actual surface of the way, it may still, in many cases, be made to serve as a foundation, on the top of which there may be placed a layer, having a depth of 2 or 3 inches, of broken stone, if need be, of a

[1] Preliminary report on the geology of the common roads of the United States, Fifteenth Annual Report United States Geological Survey, pp. 255–306.

kind which has to be brought from a distance. This combination of low-grade material, which may be made to unite in a substantial manner, but which may be unable satisfactorily to resist the tread of the wheels and the feet of draught animals, with a harder overlying coating will often cheapen the cost of roads, as the experience of the Massachusetts highway commission shows, in the amount of from 20 to 30 per cent of the expenditure.

The results submitted in the tables and descriptions contained in this report are due in the main to cooperative work, in which the United States Geological Survey, the highway commission of Massachusetts, and the engineering laboratory of the Lawrence Scientific School of Harvard University have each had a share. The Federal Survey has furnished the general direction, and has borne the greater part of the cost of the field work. The State commission has provided for the pay of the officer who has been engaged in making the physical experiments, the results of which are set forth, while the Lawrence School has afforded the laboratory and the considerable pieces of apparatus, as well as the dynamic power required for the work. The field work has been so arranged that, while it might serve the immediate needs of the particular way which was under consideration, it has also been of a nature to throw light on the more general question as to the serviceableness of the various kinds of stone for use on roads. The results, as given in the appended tables, show in a general way that the information thus gained may be taken as affording a fair measure of the utility of the several petrographic groups of rocks for road making. As is noted in the text, the experimental results which are set forth in the following pages have been in many instances verified by the tests of practical experience, and many of the varieties of stone have been long used as sources of macadam and their general value has, in a rude but effective way, been tested, and the judgment of roadmasters concerning them has been made up. Others have been tried for a short period on the State roads which were constructed in 1894 and have been several months in use. These last-named trials, though they have been in process for only a few months, are valuable, for the reason that they were made under standard conditions as regards methods of construction and have been subjected to the criticisms of skilled engineers. This very practical study of the problem is one of the many advantages which have occurred through the connection of this inquiry with the labors of the Massachusetts highway commission.

In the preparation of this report I have had the valuable assistance of Mr. Logan Waller Page, who has had charge of the work of collecting during a portion of the time employed in gathering the data, and who has personally, under my direction, carried on the experiments which are set forth in the appendix; and of Mr. Frank Charles Schrader, who, during the present fiscal year, has been employed in the task of obtaining materials and determining their distribution. I have

also to acknowledge the frequent and kind assistance of Mr. William Edward McClintock, C. E., member of the State highway commission, in devising the methods of the experiments, and also in determining the value of the various stones, as shown by his long practical experience in road building.

SYSTEM OF TESTING.

As the value to highway engineers of the matter set forth in the following pages depends in large measure on the methods employed in the investigation, it is necessary to state in some detail the system which has been pursued in gathering the materials and in conducting the tests to which they were subjected. This account is made the more extended for the reason that, so far as I have been able to find, work of this nature has not hitherto been done in this country. It is therefore desirable so to set forth the plan of operations as to make it possible for inquirers to criticise the procedure or to adopt it with such improvements as their better skill or experience may dictate.

As an introduction to the account of the methods employed, it may be well to note that the adequate study of road-building materials is a task of much difficulty. At first sight it may seem best to make a practical test by using the stone in question on a roadway and for such a time as will give, in an absolutely certain manner, the endurance value of the material. The apparent simplicity and effectiveness of this method of dealing with the problem is delusive. A practical trial of a variety of rock can not be made in an efficient manner without laying a road with it for a length of several miles. Moreover, such a road should, in its circumstances of exposure to the weather and to traffic, be exposed to the same range of conditions as would be found in the case of other roads on which the material might be employed. Furthermore, such a road would, during the period of trial, have to be subjected to a very careful study in order to determine in an accurate manner the amount of traffic which it was required to bear. Experience has shown that such a census of the traffic tax on a road can not be attained within the limits of error which would give the results any definite value. Practical experiments of this nature are certain to be very costly, and are sure to be misleading.

The plan of having large practical tests of road-building stones may be subjected to the further criticism that such tests demand a method of work which in all other departments of engineering, where the resistance of materials to strain is a matter of importance, has been found utterly unsatisfactory. No one would think of trying a particular kind of iron, steel, timber, or architectural stone in such a manner. The tests are always made in the laboratory, though the data thus obtained may be criticised by the results of experience, and the methods of the laboratory may be bettered by such criticisms, as they have been and will be in the progress of this inquiry.

METHOD OF COLLECTING.

The materials which have been tested were, with few exceptions, when they came from beyond the limits of Massachusetts, obtained in the following manner: The quarry stone was, so far as possible, taken from faces sufficiently far from the outcrop surface to avoid the effects of weathering. When the deposit had not been quarried, efforts were made to obtain such a fresh face by blasting or by the use of the sledge hammer. In practice it has been found very difficult to secure materials fit for testing in cases where the outcrop had not been the seat of quarry work. This difficulty has limited the range of the study, and probably has resulted in leaving unexamined many good varieties of road-building stones in various parts of Massachusetts.

Of each deposit which has been examined, samples were selected intended to represent the average character of the material there found, and a lot of about 25 pounds was taken to be used in the experiments to determine the resistance of the stone. This was collected in bits of from 1 to 3 cubic inches in bulk, so as to obtain a better average of quality. At the same time specimens were chosen for display in a cabinet and for the study of the petrographic character of the stone.

Where the material consisted of glacial bowlders and pebbles, which in a large part of Massachusetts afford the only conveniently accessible road stone, an effort was made to obtain an average sample which would fairly illustrate the quality of the material that must be employed in road construction. Experience has shown that while it would be possible by the exercise of moderate care in selecting the bits greatly to improve the quality of the erratics used in the crushers which supply the broken stone, it is difficult to induce the men who are employed in the work to take the needed pains.

TESTS.

When the material is prepared for the tests it is broken to about the average size of the fragments used in road making. These bits to the weight of 11 pounds are then placed in the rattler or drum, so hung as to be overturned at the rate of 33⅓ revolutions per minute, which in its overturning has each end alternately lifted and lowered, so that the fragments not only rub over one another but are tossed from one end to the other of the hollow cylinder. The drum is provided with an indicator, so that at the end of 10,000 revolutions, in five hours, its motion is arrested and the abraded material is carefully separated from the remaining solid portion. Each of these parts is then weighed, so as to determine the amount of the charge which has been brought into the state of dust.

The test above described is in all essential features the same as that which has been adopted by the highway engineers of France. As the body of data gathered by those engineers is much the largest and the best ascertained that exists, it has seemed well to make this trial in accordance with the established French method, and not to make changes which

have been suggested, even where they have appeared in other respects desirable, because the results would not be intercomparable with those obtained in other countries.

In addition to the abrasion test, studies have been made to determine the value as a cement of the dust that is worn from the fragments of stone. The energy with which this fine material holds the fragments together determines one of the features that it is necessary to ascertain concerning the value of macadam which is made from any particular kind of rock. It has proved difficult to devise a proper instrument for this inquiry. The ordinary tools, known as cement testers, do not give data of value as regards the peculiar pounding action that is effected by the feet of draft animals, for the reason that they determine the resistance of the material to a steadily applied force. On this account a piece of apparatus has been devised which enables us to determine in an accurate manner the amount of the blow that is required to break up the bond in a briquet formed from the dust.

Still another test has been found necessary, though as yet it has been incompletely applied. This is designed to show the recementation value of the powdered rock when the bond which it forms in setting is again and again broken, as it is apt to be by the rude usage to which the superficial materials on the roadway are subjected. To obtain a basis of judgment in this regard the powdered rock is allowed to cement, and after becoming as hard as may be the material is broken to the state of powder; the briquet is then remade and the test repeated.

Although the studies embodied in this report have not as yet attained to anything like completeness, it will be well now to consider their probable relative value in determining the utility of different kinds of rocks to be used in making roads. A careful inspection as to the effect which horses and vehicles have on road stone, an inspection which the writer has made in what seems to him to be a sufficient manner, shows that the damage which traffic does to a road varies somewhat with the nature of its construction. Where the wheelway is paved with blocks of stone, the pieces being fitted closely together, resting on a firm foundation and with the interspaces properly filled with asphalt or other material that will prevent the motion of the separate stones, the damage to the roadway is limited to the result of the blows of shod hoofs and of the compressive and shearing motion of the wheels combined with the stroke which the tires deliver as they come against the edges of the block. Observation shows that the stones used in block pavements wear but little in the central portion of their exposed faces, the greater part of the abrasion taking place on the edges, where the percussive action of the horses' feet and of the tires, as well as the shearing work, is most effective.

Where the stones are used in the cheaper and therefore more generally available methods of macadam, the conditions that determine the endurance of the pavement differ much from those which obtain in

the system of block construction. The reasons for this difference are as follows: In a macadam pavement, the stone being rolled down to a smooth surface, the shearing action of the wheels, except under rare conditions, is slight, there being no considerable intervals between the crowns of the separate bits to serve, as in the case of the block pavement, to bring about a sliding motion of the tires. Thus the effect of the traffic on the actual surface is principally wrought by the blow of the horses' feet and the compressive effect of the weight of the vehicles applied through the small field of the tires which actually rest on the roadway. The other differences arise from the dependence of the macadam method on the measure in which the bits of stone are held in their bed places. This holding is in small part brought about by the packing of the stones together under the treading action of the roller. As may be ascertained by inspecting a macadam road where stones, say 2 inches in diameter, have been rolled until they are as firmly compacted as possible, these bits, though they may appear to be firmly held, are not really well fixed in their positions. If the experiment is made before the material has been wetted, it will be found that the bits readily separate from the mass. Such a road, after a little travel, becomes a mere rubble. If, however, the surface is covered with dust—or what comes to the same thing, with fine stone, which is rolled until it is in a powdery state—and especially if this powder is wetted and forced into the underlying mass by the roller and the roadway is then allowed to dry, the separate fragments of stone, if the material be good, will remain in place until they have been completely worn away by the action of the wheels. It is thus evident that the cementation value of the powder produced by grinding the stones is a matter of much importance. The recementation value, or the capacity of the material again to set with many repetitions after it has been broken up, is of value for the reason that it determines the extent to which fragments that have from time to time become loosened may again be bound together into the solid mass of the road by the reuniting of the powder when it is wetted by the rain. Moreover, where the powdered stone has a high recementing capacity it tends to form a somewhat enduring coating on the surface of the road, which in a measure protects the firm-set underlying bits from the blows of the horses' feet and such shearing action as the wheels may apply. Thus a macadam road whose material passes into a powder which does not recement in an effective manner will have its dust quickly blown away and will wear much more rapidly than a road which is made of a stone whose detritus continues to cake in a firm manner, however often it be ground to the powdery state.

The foregoing brief account of the conditions which determine the endurance of a street pavement will serve as a foundation for the consideration as to the value of the experiments which are set forth in the later sections of this report. It will be observed that these

experiments do not give any tests having for their purpose the determination of the elasticity of the stone, or in other words, of the extent to which it will sustain weight without going to pieces. The reasons for the omission of this test are as follows: In the first place, save under very unusual conditions of traffic, the amount of weight which is applied by the heaviest loaded vehicles to a roadway is likely to be well within the limits of the elasticity of any stone which a discreet roadmaster would undertake to use in any highway work. It may be assumed that, save in cases of error as to the choice of material, the masses used either in block or macadam work will, if properly bedded, be relieved from the danger of crushing from compressive strains. It may furthermore be said that no apparatus has as yet been contrived which will give, except at very great expense, any proper measure as to the average elasticity of the stone—information which would be of service to the roadmaster. It is true that in the case of architectural stone, where the masses are carefully selected, tests as to elasticity are of great value and can be obtained at a cost which is not disproportionate to the advantage that is gained. But with road stones, where the material has to be taken with little or no selection, it would require an averaging of scores, if not hundreds, of trials to give results of an indicative value.

The test by the abrasion of the stone in the revolving drum is, as may readily be seen, not closely like that to which the material is exposed on the surface of the roadway. The weight of the masses which are moved over one another and the nature of the movement alike differ in a very important way from the conditions which affect the roads. It would be desirable, though as yet it appears to be impracticable, to construct apparatus which would imitate the action of the wheels and horses' feet. It is doubtful, indeed, if by any method short of building a considerable road so arranged that all the materials abraded by traffic could be preserved and weighed any satisfactory determination would be possible. The method used rests upon the assumption that the wear inflicted on the fragments of stone by the rotation of the drum bears a definite ratio to that imposed by the more powerful action of the wheels operating on the roadway. It is highly probable that within the limits required by the road-builder's art the abrasion rate of stone is proportional to the amount of energy applied to grinding off particles from its surface. The French, who invented and have for a long period made use of this test, are content with the results. We may therefore assume that, for the present at least, they may fairly be made use of in this country.

The cementation and recementation tests appear to be sufficient for the end in view. They certainly give a basis for the determination as to the firmness of the bond which unites the bits of the macadam together. They show also, in a general way at least, the extent to which the powdered rock is likely to remain on the surface of the road as a protective coating. Moreover, these experiments indicate that it

may be desirable in certain cases, where a stone otherwise suitable for macadam purposes does not afford from its powder a good cement, to cover the road with dust made by grinding some other variety of stone which will afford a firmer bond. It may also be said that these experiments on the binding value of the powdered rock add to the other considerations which lead us to believe that we can not well trust to the formation of rock powder between the bits of stone through the action of the roller in grinding the fragments together, but that experiments should be made looking to the introduction of such powder between the stones before the rolling is begun. An inspection of a section through a newly rolled road shows that the amount of finely divided rock in the lower part of the section is generally insufficient to insure effective cementation. At present the trust is in applying "fines" to the surface, the material being crushed by the roller and, when wetted, worked down into the interspaces between the stones. As the voids in the lower part are imperfectly filled the adhesion in that zone is weak, and the interspaces are apt to gather water, which in freezing disrupts the roadbed.

It should be said that the tests made upon building stones have to be estimated, as regards their value in reference to a particular piece of road construction, by the peculiar conditions of traffic to which the road is to be subjected. Thus, experience shows that where a road receives only a moderate amount of wear, where the teams which pass over it are not numerous and bear no very heavy burdens, the harder traps are likely to prove rather less serviceable than the softer materials. It is, indeed, not improbable that in certain parts of the State, where the traffic is light, it may prove a better policy to use the soft rocks, such as the mica-schists, rather than the more resisting materials. In such cases it will be found that an equation has to be made of the hardness and of the cementing value of the substance. Where the two tests both show as low, it may be assumed that the material is unfit for service in any form of highway construction. Where, however, the binding power is high, though the resistance to abrasion is not so, it will often happen that the rock is worth consideration, especially where a substitute would have to be brought from a considerable distance.

The importance of the considerations just above noted may be reckoned from the experience which has been had in this and other countries in using coral rock in highway construction. Stone of this nature is very soft. It readily pulverizes under the wheels, but the powder thus formed, having the property of binding after having been wet and dried, forms a coating which serves very well when not subjected to the weight of heavy vehicles.

GENERAL ACCOUNT OF THE ROAD-BUILDING MATERIALS OF MASSACHUSETTS.

In the following pages a description will be given of the various classes of rocks occurring within the limits of Massachusetts which may be advantageously used on highways. Incidentally reference will be made to materials which may be made to serve on the less-traveled traffic ways and on sidewalks. Although the account of the materials suitable for road making within the limits of Massachusetts will be set forth mainly according to their regional distribution, it will be necessary to consider the superficial accumulations of glacial waste somewhat apart from the other materials, after which a general account will need be given of the dike stones, to be followed by that of the bedrocks.

ROAD-BUILDING MATERIALS OF GLACIAL ORIGIN.

Although the thickness and character of the glacial drift in Massachusetts varies much in the different parts of its area, no portions of its surface except those which are water covered, those occupied by bogs, and those formed by recent accumulations due to water or wind action, such as the alluvial terraces, the sand spits, and dunes, are quite without glacial débris. In more than nine-tenths of the area of the State the glacial deposits are worthy of search as sources of road-building materials. It is therefore necessary to preface the general account of these ice-made accumulations by some statement as to the circumstances of their origin and distribution.

The greater part of the glacial waste found in Massachusetts, whether measured by area or by quantity, consists of what is known as till or bowlder-clay, a kind of waste composed of fragments of stone varying in size from the largest bowlder, which may contain many thousand cubic feet, downward in size to the very fine bits which are commonly known by the name of clay. These diverse materials are found forming in general a confused coating, which varies in thickness from a few inches to a hundred feet or more. The fragments of this till were worn from the rock by the passage of the ice over the surface; they were commingled with the mass of the glacier, and when it melted away they were dropped upon the surface where they now lie.

It is easy to see that the fragments in the till have been subjected to a rude testing which determines their relative strength at the time when they were broken from the bed-rock. The evidence goes to show that these bits were subjected to yet further stress while they were in the ice, the irregular motion of that mass serving to grind the fragments against one another. In this way it has come about that in a mass of till the pebbles and bowlders, which often constitute by far the larger part of its bulk, are, or at least were immediately after their separation from the bed rock, the harder parts of the material. All the weak bits are likely to have been reduced to the state of powder. On this account

the bowlders of the till are, except where they have been long exposed to the weather, prevailingly of a more uniformly solid nature than are the quarry rocks from the same sources of supply.

Next after the till, both in volume and in area of distribution, come the deposits of washed drift, i. e., of glacial waste which has been subjected to the action of streams of water which poured forth from beneath the ancient glaciers and flowed for great distances both beneath the ice and beyond its front. In general, this washed drift contains a much less amount of pebbly and bowldery materials of a nature to be serviceable for use as road-building stones than does the till. Where pebbly the fragments are usually of small size, and in most cases the flinty matter (that is, of material on the whole unsuited to road making because of its brittleness and the lack of binding power in the powder which it makes) predominates. Here and there, at points where the current action was particularly strong, the fragments may be of considerable size. This is especially the case in those accumulations which were formed in the caverns that afforded ways for the subglacial rivers. At many points in New England and elsewhere the ancient subglacial arches are still traceable through the extensive deposits of detritus which have been accumulated in them. (See Pl. XVIII.) Owing to the fact that the subglacial streams generally flowed with great energy, the masses of rock which these deposits contain are often of large size. Not infrequently the greater part of the accumulation is made up of bowlders averaging more than a foot in diameter.

As might be inferred from their history, the fragments in the washed drift are usually of more durable nature than those found in the till. It needs, however, to be noted that in this waste the materials of a quartzose nature are more apt to survive the stresses to which they have been subjected than are those of the other species of rocks. As will be seen from the tests, the slight binding power of quartz dust and the ease with which the material is fractured make this species essentially unfit for use in the construction of macadam roads. It may be further remarked that, except in the deposits which were made in the old ice caves, the washed drift generally yields pebbles of small size, usually so small that they can not be profitably employed for making crushed stone. Where the accumulations were formed at a considerable distance in front of the glaciers from which the streams came forth the pebbles are commonly less than an inch in diameter and are thus worthless in road making.

The third group of glacial deposits which deserves attention here is that formed in front of the ice, having the character generally denoted by the term frontal moraine. Although these accumulations commonly contain a considerable amount of till and of washed detritus, they are characteristically composed of stones, often of large size, which were pushed forward by the ice or dropped along the margin of the glacier in consequence of its melting. These masses of stone are often accu-

CROSS-SECTION THROUGH A SERPENT KAME OR ESKER; WESTON, MASSACHUSETTS.

mulated without order and with many interspaces, the whole bearing the aspect of a ruined wall of cyclopean masonry. (See Pls. XIX, XX.) Such deposits often afford great accumulations of stone which are as convenient for the quarryman's use as they would be if they lay in their original bed places. Not infrequently in New England they have been used as sources of building stone.

The value of the drift deposits as sources of rock to be used in crushed form depends to a great extent on the amount of decay to which they have been subjected since they were brought to the position which they now occupy. Although it has been but a few thousand years, possibly not more than ten or twelve thousand, since the glaciers disappeared from New England, and perhaps not much longer since they passed away from the more western portions of the United States, the amount of decay which has taken place in these originally very solid bowlders and pebbles is, though variable, often very great. In many cases it makes the materials essentially unfit for road building. It is therefore important to note certain features in the distribution of this decay as regards the kinds of rocks, their relations to the surface, and their areal distribution.

In general it may be said that the smaller bowlders, other than those of quartz, which have lain on the surface of the ground since glacial time, have, by decay, often been rendered unfit for use on highways, except where they can be placed in the substructure. When broken they are too soft to resist the action of the wheels or of the horses' feet. Both on the surface and underground the decay is greatest in those rocks which contain considerable amounts of iron in other than the form of magnetic oxides and those which are made up in considerable parts of the species of feldspar which readily pass into the state of kaolin. In almost every part of New England a close observer will note places where large bowlders presenting these conditions have so far fallen to pieces that masses originally solid, having a content of 200 or 300 cubic feet, have broken down until they form low mounds of rubble.

The decay of rocks on or near the surface is often much hastened by the action of the roots of trees, which penetrate the crevices, carrying with them the conditions of chemical change. There is also a general opinion in New England that the splitting of bowlders is often brought about by the action of lightning. I have been shown a number of instances of this sort in which it was difficult to explain the rending of the masses, appearing as if done by the action of gunpowder, by any other supposition than that of a heavy electrical discharge, which, by vaporizing the water along the rift planes of the mass, had, in a manner, exploded it.

The amount of decay in the superficial drift in New England decreases in an evident way as we go from the southern border of that district northwardly. It is thus much more evident in southeastern Massachusetts than in New Hampshire. It appears to me more distinct in the

southern portion of the last-named State than along the border-line of Canada. This, it may be remarked in passing, is one of the evidences that the ice endured in the northern part of this country longer than it did in the southern part.

The maximum of decay is exhibited by the bowlders which lie on the surface of the ground; the action diminishes with the depth of burial down to the level to which the process of oxidation has penetrated. In cutting through a considerable section of drift materials, it will be observed that the upper portion always shows the effect of the changes brought about through the action of the atmosphere and of water. The depth of this changed zone varies in a great measure according to the character of the fields, as affecting the penetration of the oxidizing agents, and their distance back from the ice front. Thus in southern New England the alteration is visible to the bottom of the deepest section of washed drift and may be traced in the till deposits to the depth of from 16 to 20 feet, the difference being due to the relative porosity of the materials. In northern New England the penetration of decay is, in the till at least, much less evident, the zone of decay not usually extending to the depth of more than 4 or 5 feet in the till, while the washed drift occasionally shows apparently unchanged condition at the depth of 20 feet below the surface. In general it may be said that the materials from the washed drift are of a less satisfactory nature, on account of the decay to which they have been subjected, than those from the till.

Owing to the prevailingly open nature of the materials accumulated in the frontal moraines, where, as before noted, there are often interspaces between the fragments of the débris, as well, perhaps, as to the fact that the stones have more commonly been transported in the upper parts of the ice, the decay of the fragments is often much greater than that exhibited in the other classes of glacial waste. (See Pl. XX.)

Experience in highway construction shows, at least so far as New England is concerned, that the surface bowlders of small size are in general so far decayed that, whatever their original constitution may have been, they are not now in a suitable condition for road making. It is usually possible, by a careful selection, to pick out the useful from the useless mass, but this discrimination can rarely be exercised in a profitable way. As it may in some instances be useful, and indeed necessary, to make the effort to effect this separation, a description of a simple test may well be given. This can be made in the following manner: Taking a light sledge hammer, the inquirer should proceed to break in succession, on a line across the field from which the stone may be obtained, bowlders to the number of, say, one hundred. Where these stones crumble under the stroke, falling into numerous bits, and at the same time the fragments are readily powdered by light blows of the hammer, the bowlder may be regarded as worthless. Where the breakage occurs along one or two distinct planes and the pieces are not

VIEW OF A FLAT-TOPPED MORAINE; DOGTOWN COMMONS, CAPE ANN, MASSACHUSETTS.

in turn easily broken, it may be assumed that decay has not materially harmed the stone. After a few tests, the observer will learn to know by the sound of the hammer the condition of the bowlder; he need not, indeed, be at the trouble of breaking it.

If, with the use of the test above described, 90 per cent of the field stone proves to be in sound condition, the source of supply may be deemed fit. Care, however, should be taken to enforce on the men who collect the stone caution in their work. This is most readily accomplished by rejecting decayed stone which has been brought to the crusher. With a very little practice the most untrained eyes and hands can learn, without the use of the hammer, to know the difference between a fragment which is sound and one that is worthless.

In certain instances, as in the roads on the island of Marthas Vineyard and on Cape Cod, where the traffic is light, and where good road-building stones would have to be transported from great distances and at great cost, the Massachusetts highway commission has deemed it best to macadamize the road with stone taken from the fields or moraines. Experience has shown that much of this stone breaks into fine bits in the process of crushing; in fact, the amount of the fines thus produced is much greater than the share of the material which can be employed in surfacing the roads. It has been found, however, that this fine stone can advantageously be used in place of gravel in covering the shoulders of the highway.

It will occasionally be found advisable to use "field stone," even where it is much decayed, and this with the expectation that the repairs are likely to be rather frequent. In such cases computation as to the relative cost of good and poor stone, the reckoning extending over a term of years, is necessary to insure a wise determination of the question.

In determining by a rough mineralogical inspection the relative value of bowlders, or, as they are well called, field stones, it may be assumed that those in which feldspar is the predominant mineral are of the better sort, and this for the reasons that the material is relatively not very brittle and that the dust which it forms has a considerable coefficient of cementation. Where hornblende or the related augite exists in considerable quantity the hardness of those minerals is advantageous, and though their direct cementing value is small, the iron which they contain serves indirectly as a binding material.

Where, as is often the case, the rock is micaceous, it is always, and in proportion to the amount of that substance, less valuable than it would otherwise be, for, although the mica does not rapidly grind up under the wheels, in a state of dust the small flakes of it are readily blown or washed away. Wherever the rock contains a large amount of ordinary quartz it thereby falls into the lower grade of value, for the reason that this mineral is very brittle and the particles of its dust are without cementing value; they are, moreover, relatively light and are easily borne away by a current of air or water.

There is a certain measure of damage consequent upon the use on roads of macadam derived from field stone, which is due to the variable hardness of the fragments, arising from the usually great variety in the mineral character of the bits. In practice it is found that some of the stones always prove relatively soft, and thus wear out under the impact of the wheels and the feet of draft animals, leaving small depressions, which, if not promptly repaired, are apt rapidly to extend. Other very hard bits are left projecting as the softer material wears down, and these, for lack of adequate support, are sure to work out and encumber the way. Both these processes hasten the wearing of the road. This evil can be in a great measure reduced by the use of a large share of the "fines" or gravel-like material produced in the process of crushing. This detritus is generally formed in such quantity during the preparation of the first coat of macadam that enough remains over, after applying a top dressing of proper thickness, to recoat the road for several years after its construction. Experiments made by the Massachusetts highway commission in 1894–95 indicate that the production of fines is so abundant that the surplusage beyond that required properly to complete the road is likely to be sufficient, where the macadam is made from field stone, to resurface the road in a complete manner on three or four occasions.

Where possible, as it often is, to make a selection of varieties of field stone which are to be used in road building, it is desirable to use each class separately for macadam purposes, by constructing the road in distinct sections, each being built of the fragments obtained from one kind of rock. In this way the difficulties arising, as above noted, from the varying hardness of fragments is avoided, and at the same time an excellent experiment is instituted as to the relative values of the different grades.

SYSTEMATIC DESCRIPTION OF THE DRIFT MATERIALS IN MASSACHUSETTS IN RELATION TO THEIR USE IN ROAD BUILDING.

We now have to consider the distribution of the drift materials in Massachusetts so far as that feature relates to road-building problems. This relation is established in two ways: In the first place, by the character which the drift coating may give to the foundations of the road, and, in the second place, by the nature of the supply of material used in the manufacture of macadam which may be obtained from the glacial detritus. It will be proper to make the statement concerning the road-constructing value of the drift pebbles and gravel in most detail for those sections of the State where it will be necessary to use the products of the glacial deposits in road construction, and this for the reason that bed-rocks of the nature to afford good varieties of road stones are not economically accessible.

Before entering on the description of the drift of Massachusetts by areas it will be well to examine briefly the main causes which have

ORDINARY FORM OF MORAINE; DOGTOWN COMMONS, CAPE ANN, MASSACHUSETTS.

served to determine the considerable and, from our point of view, very important differences which exist in this débris in the several natural divisions of the State lying between its western boundary and the extremity of Cape Cod.

The differences in the character of the drift pebbles in the sections which we are about to consider depends in part on the nature of the subjacent rock in each field, on the distance of carriage of the débris, and on the nature of that conveyance, whether by ice or by subglacial streams. These complicated conditions will be taken into account only so far as is necessary to give a profitable meaning to the economic points which are to be dealt with in this report.

The State of Massachusetts is, as regards the distribution of its drift deposits, as well as its other geological features, divided into the following distinct regions: The Berkshire district, including the region from the margin of the Hudson Valley to that of the Connecticut Valley; the Connecticut Valley, a broad interval of lowlands lying between the Berkshire district and the central portion of the State; the Worcester district, or central highlands, occupying the area between the western margin of the Connecticut Valley and the eastern border of the coastal lowlands, or extending in general to a north-and-south line drawn through the towns of Pepperell, Ayer, Marlboro, Hopkinton, Milford, and Blackstone; the eastern lowland, comprising an area underlain by the ancient hard rocks, extending to the shore, along the coast between Newburyport and Duxbury; and, finally, an eastern lowland and peninsular district, including the greater part of Bristol and a portion of Plymouth counties, as well as all of Cape Cod and the adjacent islands, in which the ancient hard rocks lie, so far as known, altogether below the level of the sea, and where the supermarine strata are composed mostly of glacial drift and certain soft rocks of Cretaceous and Tertiary age.

BERKSHIRE DISTRICT.

This portion of the State is occupied by a series of mountain ranges which are the southward continuation of the Green Mountain system. As will be noted more particularly in the statements concerning the quarry stones of the State, the rocks of this district are prevailingly either too soft, too brittle, or of too little binding power to make them well suited for use as broken stone. As the drift of this district has evidently been transported from a much less average distance than that which occurs in the lower-lying parts of the State, the pebbles and bowlders are likewise rather unsatisfactory sources from which to obtain stone to be used in road making. Nevertheless, for reasons previously given (see page 291), these pebbles afford in most cases a source of better supply than can possibly be obtained from the quarry rocks.

The greater part of the drift in the Berkshire section is of the till type, and practically all of the glacial waste above the floors of a few main valleys, such as the Housatonic, the Westfield, and the Deerfield

rivers, is of this nature. These fields of till offer the most troublesome districts in the State for the construction of roads, and this for the reasons that the foundation for the roadbeds is poor and the materials for construction to be obtained from the till are of rather unsatisfactory quality. Owing to the extreme coldness of winter and the rather limited snowfall, frost penetrates to a great depth. The glacial detritus, which generally covers the country to the depth of 10 feet or more, is of a very clayey nature, holding such an amount of water that the heaving action of the frost is sufficient, each time a thaw occurs, to break up the foundations of any road which is not well drained.

As the pebbles and bowlders which occur in the Berkshire district are formed from rocks which are generally quite accessible to decay, the surface or field stones are, on the whole, not of good character, their long exposure to the agents of decay having caused them to rot very generally to a depth of some inches below the surface. It is therefore desirable, where pebbles or bowlders are used, to obtain the masses from a depth of 2 or 3 feet, at least, below the surface. In most parts of this district these larger fragments are relatively of such infrequent occurrence in the finer and unserviceable materials that it will rarely be profitable to sort the materials of the pit in order to obtain a supply for the crusher. Here and there, however, small fields of a somewhat morainal nature, though of a till-like character, afford a plentiful share of fragments.

In many parts of the Berkshire area which are otherwise unprovided with suitable stone, resort may be had to the beds of the streams where long-continued torrent action has separated quantities of the harder bowlders from the till débris, leaving these well-selected fragments in a condition which is tolerably well suited for use in the crusher. In most cases these torrent pebbles do not lie convenient for exploitation, but in many instances, especially where brooks with steep beds enter larger streams having a less rate of fall, the accumulation of such pebbly matter is very large. Unfortunately, in nearly all instances this store of water-assorted waste is so placed that the macadam prepared from it has necessarily all to be hauled up the grade in order to find its place in the roadway. Notwithstanding this inconvenience the detrital cones of these torrents will be found in many cases to afford the best sources of supply.

The stream deposits above alluded to occur most abundantly in the brook beds which extend from south to north. They are very scantily developed in those valleys where the streams flow southward. The reason for this peculiarity of distribution of the bowlders is to be found in the fact that since the Glacial period this region has been tilted up to the northward to such an extent that the rate of fall of the streams is so far lessened that they can not keep their beds clear, while in the case of the streams that flow southward the descents have been materially

increased, with the result that the pebbles are driven forward for an indefinite distance. In the beds of the northward-flowing streams the accumulation of bowlders often exceeds 15 feet in depth, and the alluvial plains which they form are not infrequently 100 feet or more in width.

The washed gravels of the Berkshire district are, as before noted, essentially limited to the greater valleys; they particularly abound in those of the Westfield and Greenfield rivers. In both of these valleys pebbly stream deposits, as well as pebbly kames or eskers, where the fragments are large enough to be advantageously used in the crusher, so abound that rarely is it necessary to go a greater distance than a mile in order to find a tolerable supply of such materials, which, by mere sifting, may be made ready for use in the crusher. In these valleys, however, it is in most cases best to resort to the river beds, where it will be found that the waters have effected a concentration of the washed drift substantially like that above described as brought about in the torrents by the wearing away of the till deposits. The Massachusetts highway commission has constructed in the town of Shelburne a considerable section of road of which the macadam was formed from the so-called "hardheads," or water-rounded bowlders of glacial origin, obtained from the bed of the Deerfield River.

On the sand plains which occupy the lowlands of the greater valleys the foundations for roads are generally good. In some cases, however, river-made clays lie very near the surface, as in a great part of the way between North Adams and Williamstown. In yet other cases, during the times when the streams are full these sands become so surcharged with water that they almost become true quicksands, and therefore afford very unsatisfactory foundations.

The local variations in the glacial deposits in the Berkshire district are considerable. Thus, in the till material along a line from the eastern portal of Hoosac Tunnel southward to the Connecticut line the pebbles and bowlders are, to a considerable extent, made up of débris from the granitic gneiss which outcrops in a belt lying generally to the westward of the line above noted. So far as the drift contains these pebbles, which it often does in a large proportion, the fitness of the material as a source of stone for use in the crusher is distinctly increased.

Along the limestone belt which lies to the westward of the Housatonic Valley and has a northward continuation about North Adams, crystalline limestones occur plentifully. The drift materials from these rocks are naturally of a soft character, and have in most cases been considerably affected by decay. They are quite unfit for use in the crusher.

Throughout the greater portion of the Berkshire area the rocks are mica-schist or of a very gneissic character, materials which are equally poor for road making. As before remarked, the pebbles and

bowlders are better than the bed-rocks, and on this account alone are worth attention. Unfortunately, in this field of the Berkshire Hills trappean rocks, which occur plentifully in the same ranges in Vermont, are singularly lacking. There are a few dikes, but these occupy such a small area that they make no noticeable contribution to the drift.

CONNECTICUT VALLEY.

The drift deposits of this valley to a considerable extent consist of materials which have been arranged by river action since the ice-sheet retreated to the north of the Massachusetts line. Where these fluviatile deposits occur they are generally of sand or of clay, and not only afford a bad foundation for roads but fail to furnish any materials which may be employed in their construction. Probably not more than one-tenth of the lowlands of this area is occupied by till or by coarse materials, such as are deposited beneath the ice arches in the manner noted on page 292. By far the greater part of the pebble-yielding drift lies on the flanks of the valley, where the river plains and terraces pass into the hill country. On these slopes the till is often quite thick and contains excellent materials for use in road making. It may be said, in a word, that the pebbles and bowlders which they afford have a value at least 50 per cent greater than that of any which can be found in working quantities within the Berkshire district.

The reason for the better character of the drift materials in the Connecticut Valley is to be found in the existence beneath this basin of two groups of rocks which, when they underwent glacial abrasion, yielded material of a peculiar character, of a kind suitable for use on roads. These deposits consist of widespread conglomerates, which abound in this field, and of trap rocks, which likewise are widely distributed and are of excellent quality for service in the construction of highways.

On some accounts the most serviceable deposits of pebbles and bowlders are those which occur in the form of deltas or detrital cones lying where the streams from the highlands, particularly from the eastern side of the valley, debouch upon the lowlands. On the western border these detrital cones are in the main made up of the waste from rather soft rocks, those which outcrop in the Berkshire district. On the eastern side the materials are, to a considerable extent, fragments which were carried up into the Worcester highlands from the valley by the ice and have afterwards been recarried back toward their place of origin. The fitness of these materials for road building increases southwardly from Turners Falls toward the Connecticut line.

The kame and esker bowlders of the Connecticut Valley are of relatively small importance, the greater portion of such deposits having been covered by the river sands and clays, although the accumulations of this nature which exist in the valley have much scientific interest.

They, as well as the till materials, are of little economic value, for the reason, as will be noted in the account of bed-rocks, that the traps are so abundant and so widely distributed within the area.

THE WORCESTER HIGHLANDS.

This district lies between the Connecticut Valley and the coastal lowlands. Like that of the Berkshire Hills, it is, to a great extent, deeply covered with till deposits, but, unlike the last-mentioned area, the bowldery material has generally been derived from a considerable distance to the northward, largely from beyond the confines of the State. In the section between the western margin of this district and the neighborhood of Worcester the drift is, to a great extent, made up from the waste of schistose rocks, the material being in general of low value for use on roads. By careful and systematic culling, field stones in suitable constitution for road making can be gathered to the amount of about one-third of the bowlders exposed to view. Where the whole of the material is used, the roads can not be expected to endure a heavy traffic in an advantageous manner. In this portion of the district a considerable part of the till is contained in those curious lenticular hills known to geologists as drumlins and locally called "hogbacks." These deposits, each an unstratified mass of clay, sand, pebbles, and bowlders, often attain a thickness of 100 feet or more.

It is characteristic of the drumlins about Worcester, as well as of those which occur in other fields, that the fragments of rock contained in them have often been brought from very much greater distances than those which are found in the till. Thus, in the lenticular hills which we are now considering the bowlders are, to a great extent, from tolerably hard rocks lying in New Hampshire. Not only are these bowlders of the drumlins of originally better constitution for the purpose we have in view than those which are commonly found in the field, but where they are taken from below the surface they are much better preserved from decay. The result is that where, as is sometimes the case, these lenticular hills contain a large proportion of bowlders, their deposits may be advantageously worked as a source of supply for the crusher.

In the region immediately about Worcester there appears a set of hard quartzites and gneisses, apparently highly metamorphosed rocks of Carboniferous or earlier Paleozoic age, which are the source of drift material better suited for road making than any occurring in the western part of the field. Experience, however, shows that these pebbles, when crushed, yield an excessive amount of very finely divided material—much more, indeed, than can possibly be used as the top coating of a road composed of coarser bits of crushed stone.

From Worcester eastward to the ill-defined border of the district the quality of the pebbles contained in and on the hills, as well as in the local modifications of the mass in the drumlins, steadfastly improves,

the gain being due to the rapid diminution in the quantity of the schistose element in the underlying rock and to the gradual introduction of the harder granitic, gneissic, and quartzitic rock, as well as to the coming in of trappean materials, which were lacking in the western portion of the field. Thus it arises that the eastern section of the Worcester district affords tolerably good field stone.

The washed gravels of the Worcester district are considerable in extent, mostly occupying the valleys of the streams, though in the region to the northwest of Worcester they have gained a noteworthy extension in the upland country. In every town in this section of the State there occur in greater or less development eskers or elongated ridges of detritus which, as before remarked, were laid down in the old subglacial river channels. For some reason not yet determined these singular ridges are more abundant in the Worcester district than in any other tolerably high part of this country. To a considerable extent these eskers are made up of coarse pebbles and bowlders which have been derived from the New Hampshire rocks. Such deposits, where they lie convenient for use on roads, may well afford material which, after proper screening, will be suitable for use in the crusher. In all the instances known to me the stone in these eskers is very much better in quality than that which can be obtained in the open field. Not only when crushed will the amount of "fines" be relatively small, but the roads built from this source of supply will most likely prove nearly twice as enduring to heavy traffic as those which are made from ordinary field stones. This difference will probably far more than repay the cost of extracting and sifting the material, at least in those instances where the transportation is not a matter which needs to be taken seriously into account.

In certain portions of the Worcester field, particularly on its eastern margin, the local concentration of the bowldery materials effected by the action of torrents is so considerable as to deserve the attention of roadmasters. As a whole, these torrent concentrations are of less importance than they are in the Berkshire district, but in many places, especially where the small streams enter considerable valleys, they have accumulated deposits which are likely to prove of value in road making.

COASTAL LOWLAND.

This section of the State is not clearly delimited from that on the west. It is composed of the low hilly country which rather gently passes into the Worcester highlands on the one side and beneath the sand accumulations on the east and southeast. It attains the shore along the western portion of the field which lies on Buzzards Bay, and again between Plymouth and the mouth of the Merrimac River. In this part of the State, for the reason that the surface is very irregular and the bed-rock extremely varied in character, the nature and local conditions of the drift are much more varied than in any other part of

Massachusetts. In general it may be said that about two-thirds of the surface is occupied by till and the greater part of the remainder by washed drift. There are also considerable areas that have a true morainal character.

The till of the lowland terrace is so varied in constitution that no single statement concerning it can be made which will apply to all parts of the field. It may in general be said that its composition is extremely varied, a given cubic yard of the mass often containing fragments which range in quality from the very best to the very poorest that can be used in road making. In this portion of the State more than in any other district a deliberate and painstaking choice of the pebbles which are to be crushed is most necessary. In general it may be said that the quality of these detrital materials improves as we pass to the eastward. On the western border, where a large part of the detritus has come from the Worcester district, the amount of rejectable matter is decidedly greater than in fields far enough away to have escaped contributions from that area.

In the section about the Blue Hills and on the island of Cape Ann the till is very largely composed of the granitic rocks commonly known as syenite. In these areas selection is hardly to be attained, so uniformly is the rock of granitic nature. Fortunately, although this material is almost too poor for use on roads which are to bear a heavy traffic, the areas are in positions favorable for obtaining a supply of good road materials from no great distance.

The eskers in this district are, as in the case of the Worcester field, remarkably abundant. They very generally contain a large proportion of bowldery matter; in some cases the proportion is more than half of the whole mass. The pebbles and bowlders from these ridges are commonly of excellent quality, representing the better class of building stone which occurs in this part of Massachusetts and in southern New Hampshire. It is owing, apparently, to the relatively great strength of the streams which flowed beneath the glacier that the eskers of this system contain a very large amount of bowldery material, the proportion being exceeded only in some of the most southern districts of the State.

In this portion of the State morainal deposits, which are very indistinctly developed in the more western portions, are found in tolerably characteristic forms. They generally occur in belts extending mainly in an east-and-west direction, and on which lie rude hills of no great height, composed in great part of large, rather angular bowlders. The most characteristic deposit of this nature is that which occupies the central portion of the island of Cape Ann and a section of the mainland extending a few miles west of the fiord which separates that area from the body of the State. Where these bowldery masses occur the fragments are likely to be much decayed; on Cape Ann, owing to their considerable exposure at the surface, many large masses have crum-

bled into the state of coarse sand and small, angular pebbles. Below the level where the stones are directly exposed to the action of the atmosphere their condition of preservation is generally good, and as the process by which they have been brought to their present position is one which has accomplished a certain selection of the harder materials, the buried portions of these moraines often afford very good varieties of rock for use as crushed stone. In this district, however, the opportunities of access to the deeper-lying bed-rock of excellent constitution for use on roads are such that the morainal heap will rarely be called on as a source of supply.

SOUTHEASTERN DISTRICT.

This field includes the greater part of Bristol and Plymouth counties and the whole of Barnstable, as well as the neighboring islands. In this portion of the State, as the bed-rocks do not rise above the level of the sea, or at least are not exposed in that position except in the case of certain soft beds of Cretaceous and Tertiary periods which have no value in road building, the glacial deposits afford the only sources of road-building materials, except those which may be drawn upon in the other parts of the country. It will therefore be well to consider the nature and distribution of the pebbly and bowldery deposits in this district in a somewhat more detailed manner than has been essayed in treating of the other divisions.

The most noticeable peculiarity of the drift of this section is the relatively great importance of the morainal deposits, which are more extensive and are built along a greater number of lines than in any other part of New England. Except in the case of Long Island and New York, they occupy a greater share of the area than in any other portion of eastern United States. The moraines in southeastern New England are characteristically made up of materials which have been gathered over a wide field. A tolerably careful examination of the stones indicates that the average distance of carriage exceeds 20 miles, and much of the materials which they contain appears to have come from twice that distance. For the reason that the understructure of the country from which the débris has been conveyed is generally exceedingly varied, the rocks of these moraines are in most cases of a very diversified quality, admitting of a considerable selection for the purposes of road construction.

The main moraine of this district extends from near Plymouth southward to the head of Buzzards Bay, thence along the western coast of that bay and along the Elizabeth Islands to Cuttyhunk, the southernmost of those islands. At its northern end, in Manomet Hill, the ridge attains a height of about 370 feet above mean tide, and there are considerations which lead us to believe that the base of the accumulation is from 100 to 200 feet below the sea-level. Thus, at this point the moraine has the greatest altitude of any known east of the Missis-

sippi River; it is, indeed, possible that in this regard it is the greatest of all the American ice-front accumulations. From Manomet southward the morainal deposits, though never attaining to anything like the height at the first-mentioned point, are, with slight interruptions, continued as far as Woods Hole. On the Elizabeth Islands the deposits are relatively scanty, the greater portion of these detached lands being made up of sand and gravel laid down before the last ice advance. In the portions of this moraine north of the town of Bourne, the fragments of rock of sufficient size for use as sources of crushed stone are mostly of a granitic nature, and are tolerably well adapted for road building. A small percentage of the rock consists of Carboniferous sandstone, which is worthless for the use here in view. This material, however, is readily separated, even by an uneducated person, for when found it is commonly so far decayed as to be evidently unfit for service. South of Bourne a considerable proportion of the débris is Carboniferous sandstone and conglomerate. Granitic materials, however, remain as the largest element. As a whole, the moraine above described affords an excellent source whence may be obtained road-building stones of the second grade of value.

Extending from the general north-and-south line of the Plymouth range, as above described, there is a morainal belt which forms the central portion of Cape Cod as far to the eastward as the town of Dennis. This mass is of variable width and height. On the whole the mass is much less wall-like than the Plymouth moraine. It is, however, a vast accumulation, the base of which everywhere rests below the level of the sea.

The Barnstable moraine, as we may term that which forms the backbone of Cape Cod, is composed of much more diversified materials than that last described. In the main, especially in its western section, more than half of the bowlders and pebbles which have a size great enough for use in the crusher are granitic, but are of a very firm variety of that kind of rock. This is shown by the fact that scarcely any of these fragments, though they have been much longer exposed to the weather than those of Cape Ann, exhibit any signs of decay to the naked eye. The subsidiary materials, which in the very easternmost portion of the moraine is occasionally the greater part of the mass, consist of volcanic rocks, partly dike stones and lavas, and partly indurated ash beds, doubtless derived from an extensive field of volcanic rocks which evidently lay beneath the waters of Massachusetts Bay. This last-named group of materials is of excellent quality. At certain points, particularly in the eskers, pebbles of these materials so abound that it will not be a difficult matter to sort them from the others for use on the roads.

The Barnstable moraine lies in a favorable position to afford the whole of the county good road-building stone which can be transported to the point of use by the existing railways, except in the broad fringe of sand plains which occupies the southern portion of the cape. In

portions of that field it may be necessary to haul the crushed stone for a distance of 3 or 4 miles to the place of use. In this connection it should be noted that this moraine declines rather gently to the southward, its lower portions being covered by a thin mantle of sands. It is likely that a careful search by borings may disclose various available sections of the bowldery deposits quite near to the southern shore.

On the island of Marthas Vineyard there are several important lines of moraine, of which the most important and characteristic is that which extends, with varied conditions, from near the West Chop, Vineyard Haven, to the peninsula of Gay Head. The bowlders in this moraine are mostly of granitic rock, with a small admixture of conglomerates and sandstones from the district about Dighton. Granitic bowlders, even those on the surface, are in a tolerable state of preservation, and afford as a test, both in the laboratory and in the field, a very fair road stone, the principal objections to the material being that it yields in the crusher a considerably larger amount of "fines" than can be profitably used in the first building of the road, though probably not more than can be advantageously applied to its surface between the time of original construction and that when it will be necessary to reconstruct the way.

There are two other morainal masses on the island, each of considerable extent, one occupying the central portion of the western half, between the Tisbury and the Tiasquan rivers, and the other parallel to the southern portion of the shore of the island, between the village of West Tisbury and Squibnocket Pond. There are several other inconspicuous detached morainal masses on the island, but these have no considerable importance from the point of view of road building.

Although the island of Marthas Vineyard is, throughout a great part of its extent, abundantly supplied with glacial waste of an excellent quality for road building, its area yet contains the largest district in Massachusetts which is quite without suitable road stone. In the southeastern portion of the island there is a field having an area of near 40,000 acres, where the surface is very level and where it is unusual to find a pebble having a diameter of more than 3 inches. This great plain, which was constructed by the washed sands poured into the sea from the streams which flowed beneath the glacier, may afford, as was suggested in the case of the similar area on Cape Cod, occasional buried masses of débris sufficiently coarse to serve for use in the crusher. Deposits of this nature are faintly indicated in certain slight elevations which occur at considerable distances south of the evident moraine. At present, as this plain is quite untilled, the maintenance of good roads over it is a matter of small importance, but in time, as it becomes settled, in order to avoid the great cost of transportation of road stone, it will be desirable to search out these buried deposits of pebbles.

On the island of Nantucket the only morainal mass is that which is contained in the elevated lands known as Sauls Hills. This accumulation is relatively of small extent, and lies near the eastern margin of

the island. So destitute of stone are the central and western portions of the area that it has seemed to the Massachusetts highway commission necessary to import the material for the construction of the first 2½ miles of the way between the village of Nantucket and Siasconsett. It is proposed to build the remaining 3½ miles of the road out of stone obtained from Sauls Hills. In this field the detritus, though in good part granitic, is of a tolerably solid nature, and yet is mingled with a mixture of volcanic rock, considerable in amount.

Extending to the westward from the line of the Plymouth moraine, across the western portions of Plymouth County and Bristol County, there are two or three very faintly indicated morainal belts, which are so irregularly distributed and of such slight value as sources of road-making stone that they need not be further considered in this writing.

The deposits of bowlders in the kames and eskers of the southern district of Massachusetts merit some attention. Accumulations of this nature are mainly confined to Plymouth and Bristol counties; they are scantily found in Barnstable, and are barely indicated in the island districts. The number of the ridge-like eskers in Plymouth and Bristol is so considerable, and their distribution as yet so little worked out, that only a general account of them can be given in this report.

In this portion of New England the accumulations of drift which were formed beneath and in front of the glacier by the action of the under-ice rivers are more characteristic than elsewhere in New England. As a knowledge of the facts concerning these accumulations is likely to prove helpful to those who are seeking for road-making materials, a very brief account of the conditions will here be given.

Throughout Plymouth and Bristol counties a large part of the surface is made up of sand plains, each of these plains being an area of characteristic form, from a few hundred to a few thousand acres in extent. On the southern margin of the plain the field is wide, the border is lobated, and the edge slopes down rather steeply to the outer margin. Following it northward, the plain is observed to rise upward and laterally to narrow, until it terminates at or near the southern end of a more or less distinct esker. The natural history of the structure appears to have been as follows: At the close of the Glacial period, when the ice retreated step by step to the northward, great volumes of water were discharged at the front of the glacier from these under-running rivers. The discharge appears to have been into the sea, which, during the declining stages of the ice epoch, had its level much higher than at present. The coarse material, pebbles and bowlders, borne along by the swift subglacial current lodged near the mouth of the ice caves, where, owing to the ease of escape, the opening was widened and the speed of the water diminished. Beyond the mouth of the arch the velocity of the currents was gradually reduced until the motion was so slight that the sand which they contained was deposited in the great plains, the mud being borne away by the marine currents to a much greater distance.

So far as the observations of the present writer go, all the plains in the counties last mentioned terminate to the northward in more or less important esker accumulations, which are always more or less commingled with the indistinct moraines. The clue thus given may serve as a guide to those who are seeking deposits of coarse pebbles of hard rock which may serve well in road making. In Barnstable, and in the island counties to the southward, eskers, which are the natural associates of moraines, appear commonly to be lacking. The fact is that, owing to the foundation of the moraine being below the level of the sea, the deposits which accumulated beneath the ice, or just at the mouths of the under-ice streams, have in a most complete way been sheeted over by the later-formed masses of sand. In searching for these eskers, which, as observation shows, are in some cases but slightly buried, sometimes at no greater depth than 3 or 4 feet, the observer should select those points of the plain which are opposite the breaches or very low points in the frontal moraine. In practically all cases these breaches correspond to the point of emergence of a subglacial stream, and the appropriate place for the corresponding esker is on the line of that low depression in the morainal wall.

In many cases, especially where the subglacial stream was large, the esker corresponding to a breach in the moraine is found to the northward, beyond the accumulation of large bowlders which was formed at the front of the ice.

As before remarked—and the statement can be made with even greater emphasis with reference to southeastern Massachusetts—the pebbles contained in the eskers are generally very well fitted for use in road making, for the reason that they are bits which have survived the rudest use to which the rough treatment of the ice could expose them. In most cases they were first torn from the bed-rock by the glacier and then subjected to great strains in the rude mill which exists at the bottom of moving ice. Afterwards they were taken by the under running water and urged in the most violent manner for many miles through the irregular pipes in which the subglacial stream flowed. It is easy to see that only the most resisting bits of stone would be likely to survive so rude a trial.

The till deposits of southeastern Massachusetts are of relatively slight extent, occupying probably not more than one-fifth of its surface. Here the accumulations of this nature are, in most of the fields, not so readily distinguishable from the morainal and ordinary wash drift as is the case in the other parts of the Commonwealth. Almost everywhere the till is sandy; the proportion of clay is small, and the bowlders have a more waterworn character than we are accustomed to see in accumulations of this nature. The fact is that in this section the advance and retreat of the ice have been so frequent that the same fragments are likely to have been again and again alternately affected by the action of the ice and by that of the subglacial streams. At the same time the

BOWLDERY SHORE, THE STONES BEING DERIVED FROM THE WASHING AWAY OF TILL; SCITUATE, MASSACHUSETTS.

From Gardner Collection of Photographs, Lawrence Scientific School, Harvard University.

number of these subglacial streams has been so numerous that nearly all the bits of rock have had their share of subglacial wearing in the streams, excepting those that happened to gain an elevated position in the ice and thus were unaffected, and so remained until they attained a position in the moraine.

A result of this action has been to diminish the number and to decrease the size of the pebbles in the till, and at the same time to improve their quality for use as road-building materials. Except within the limits of the Narragansett coal field, which occupies nearly the whole of Bristol County, the field stones which are obtained from the till deposits are, on the whole, of decidedly better quality than those which can be obtained from the same deposits in any other part of the State.

SEASHORE ACCUMULATIONS.

There remains to be noticed an interesting, though on account of its limited range a not very important, group of road-building stones, occurring where pebbly or bowldery drift has been subjected to the assaulting action of the sea waves. Deposits of this nature exist in considerable quantities along the greater part of the mainland coast-line of Massachusetts. In less extent they occur also on the islands. It may be noted that there are two somewhat distinct positions in which these sea-worn deposits of glacial pebbles are found. Most commonly they occur at or about low tide, lying on a rather flat portion of the bared sea bottom next the shore. The greater part of the masses commonly have the proportions of small bowlders, which by their rounding show that they have been subjected to considerable wave work. Stones less than 6 inches in diameter are not commonly found in this position unless they are firmly wedged in between others of larger size. Deposits of this nature appear to occur along about two-fifths of the coast-line of Massachusetts which faces the open sea or the wider bays. So far as observed by the writer, they are not found where the waves attain a less altitude than about 6 feet, a condition that exists only along the coast-line which received in good measure the ocean swell. (See Pl. XXI.)

The other group of sea-washed pebbles is found along the beaches, particularly those portions which receive the name of wall beaches. Usually these accumulations lie on the upper margin of the section, which is beaten by the waves in times of storm. There they form a strip having usually a width of from 30 to 60 feet, and a depth of from 1 to 10 feet. These pebble beaches are less common than the bowlder platforms; probably not more than one-fifth of the sea front of Massachusetts is bordered by them. Yet the aggregate extension of the deposits probably amounts to not less than 75 miles of that portion of the coast-line which receives the impact of the ocean surges. The pebbles in this shore deposit rarely exceed 6 or 8 inches in their greater diameter, but the major portion of them are large enough for use in a crusher. (See Pl. XXII.)

These wall beaches occur only where the conditions are such as to afford the waves a plentiful supply of fragments which are not too large to be readily swept about. In general the accumulations have been brought to their present position by the action of sea weeds, particularly kelp and rock weed, which fasten upon bits of stone that lie on the bottom at a distance from the shore-line, and have by the process of growth finally exercised such a pulling action on the fragment that it has been lifted into the control of the wave and thus brought to the shore. These wall beaches in Massachusetts are common along the shore from the mouth of the Merrimac River to Plymouth Harbor; they are lacking around the shores of Cape Cod except in its western portion; they occur again along the north shore of Marthas Vineyard, and thence westward to the Rhode Island line. The amount of material contained in these beach walls is so great that they could supply stone for all roads which are to be built that are near enough to render them accessible, the material being, because of the careful sorting out of the weak fragments which has been effected by the waves, of excellent quality for road-building uses. It should be noted, however, that where these beaches lie against bluffs of a soft nature they are often valuable elements in the defenses of the shore, and their complete removal necessarily leads to the exposure of the coast-line to the destructive action of the waves. In most instances these beaches are undergoing a constant increase in volume by importation through the action of sea weeds, as above described, so that withdrawal of the materials, such as would be made in their use for road building, is not likely to prove harmful.

In this connection it may be said that along the shores of the greater lakes there often are accumulations of pebbles which have been extracted from the drift by the action of the waves and left in the form of beach accumulation. Owing, however, to the fact that almost all the fresh-water basins of this State have had their water levels raised by artificial dams, the greater number of these accumulations are now inaccessible. Moreover, owing to the slight amount of wave action which takes place in these limited basins, the destruction of the weak fragments is so slightly effected that the remaining pebbles are but little better than those which may be obtained from the ordinary washed deposits of glacial material.

The foregoing account of the superficial deposits which owe their origin directly or indirectly to glacial action is sufficient to show that the most accessible and, on the whole, the most valuable road-building materials of Massachusetts are to be found upon the surface of the country, in a quarried state, so to speak. It may be noted that there is a collateral advantage arising from the use of these erratics, which consists in the fact that, so far as the fragments occur in the form of field stones, they are at present an incumbrance to the earth—an obstruction to the tillage of the fields. A large part of the agricul-

WALL BEACH COMPOSED OF PEBBLES; SCITUATE MASSACHUSETTS.

From Gardner Collection of Photographs Lawrence Scientific School, Harvard University

tural labor which has been expended in Massachusetts has been given to the task of gathering these pebbles and bowlders from the ground to be tilled, the materials thus removed being accumulated in the stone walls and heaps which make so conspicuous a feature in the farming districts of most glaciated areas. So far as this waste can be utilized in road building, the process is beneficial to the conditions of the fields and helpful to the interests of the agricultural class. At least three-quarters of the stone walls in Massachusetts have not been built with the object of dividing the tillage areas, but to get the stones out of the way of the plow. These fences are, indeed, a very general obstruction to the economical care of the earth. If the plan is adopted of converting this obstructive glacial waste into road material, and the method is followed for a century to come, the result will be a noteworthy increase in the value of the farm lands in the Commonwealth.

The importance of field stone as a source of road-building material makes it desirable that the persons engaged in road construction should bring much care to the system of selection of the fragments, which has been advised in the earlier part of this report. An indiscriminate use of this source of supply is likely to lead to much disappointment; deliberate and careful choice and manipulation of the materials is likely to bring about the very general application of such stone to the requirements of the roadmaster. The experience gained by the Massachusetts highway commission indicates that the difference between the first cost of constructing roads with quarry stone and with that from the field, which is of glacial origin, is likely on the average to amount to not less than 35 cents a ton. Allowing that in each twenty years the average amount of stone used upon a road is about 2,000 tons to the mile, the saving in each mile of way will be $700. Within the State the total length of roadways which within the next fifty years are likely to be macadamized is not less than 10,000 miles. This would mean an aggregate saving of somewhere about seven million dollars in each twenty years in the life of the roads. As essentially the same conditions prevail throughout the larger part of the glaciated areas of this country, the importance of this problem is manifest, even if we leave out of view the incidental benefit to the fields arising from the removal of the stones from the surface.

BEDDED ROCKS.

Under this title we shall consider the stratified rocks which are found in the several districts of the State, including in the class all deposits that originally were stratified, however great the changes in condition which the under-earth processes have wrought upon them. Thus the gneisses, although they often have an appearance which would lead to the supposition that they had not been stratified, can, in most instances, be shown to have been originally formed by the action of water; i. e., laid down as sediments on the sea floor. It

should also be noted that many, if not all, of the materials which have come to their present positions in the molten state very likely had in the remote past been in the condition of ordinary sediments. In the classification here adopted the discrimination is, in effect, between the rocks which have retained something of their original bedded character and those which, whatever their ancient history may have been, have come to their present sites in the state of igneous fusion.

BERKSHIRE DISTRICT.

The first group of bedded rocks to be noted in this district are the limestones, which constitute an extensive series of deposits occurring along the western flanks of the Housatonic Valley, and the northward extension of the same great trough, in which flows the upper waters of the Hoosac, and thence westerly to the New York line. These limestones are of a crystalline nature, and thus deserve the name of marbles. In general they are remarkably pure lime carbonates, the proportion of clay which they contain being quite small.

Tests of this stone, those both of the laboratory and of the field, go to show that in the uncombined state it is essentially unfit for use in road building. On account of its crystalline structure the material is very brittle; it quickly goes to pieces, and the powder, because perhaps of the crystalline character of the bits of which it is composed, does not readily form a cement, but tends to blow or wash away. It is not unlikely that if this material is burnt into quicklime it will prove useful as a binder, to serve in combination with some of the stones hereafter to be described from the same district, especially those known as quartzites. It seems probable also that this limestone may be made serviceable by covering the roads which are built of it with a thin layer of the low-grade iron ores which are commonly found in connection with it, usually in the form of an irregular cap on the surface of the uppermost members of the limy series. Owing to the fact that good road-building stones are lacking in this district, it is worth while to essay experiments in the combination of these limestones with other materials.

Rocks of a quartzitic character, originally sandstones which have been recomposed into a compact form, abound in this district, especially in the region lying to the west of the main valley, which extends by North Adams and Pittsfield. These materials are defective in the manner of all quartzose rocks—they are both brittle and destitute of binding power. If they prove at all serviceable it will be in conjunction with the limestones, the lime being used in its burnt form as a cement. An experiment made by the Massachusetts highway commission in constructing in the town of Lee a road of which the macadam was formed of the Berkshire quartzite has shown that even when treated in the most systematic way rock of this kind can not be made to bind in the manner required to make a good road, for, although upon

the application of the roller the fragments appear to cohere, the effect is altogether temporary, a very slight amount of travel serving to reduce the road to the state of a sandy rubble.

In the central portion of this district, in a belt of country extending from the Vermont line southwardly to that of Connecticut, through Hoosac Mountain on the north and Chester and Granville on the south, there is a belt of gneissic rock which promises to have a considerable value for road-building uses. These gneisses are prevailingly of a feldspathic nature. They contain only a moderate share of mica; they are not very crystalline. They possess, in a fair degree, the requisite hardness and toughness for road building, but their cementing quality is less than is demanded for a good road-building stone. Practical experiments with the material have yet to be made, but the laboratory inquiries indicate that, used alone, this rock will make roadways of the second order of value, and that for all except the upper 2 or 3 inches it will serve quite well in the construction of broken-stone roads.

The group of mica-schists and related rocks of a schistose nature occupies by far the larger part of this field; probably not far from nine-tenths of the surface is underlain with rocks of this general nature. So far as has been determined by field or laboratory experiments this group of rocks is of very doubtful utility for use in road building. The material quickly comes to the state of powder, the disruption being made easy by the irregular layers of mica which abound in it. There is an almost total lack of binding quality, so that unless the roadbeds which may be built of it are made extraordinarily thick they are likely to be disrupted by frost action.

Unfortunately the hill district which lies between the Housatonic Valley and the Connecticut Valley is mainly occupied by schistose rock, so that, notwithstanding the very poor character of the stone, many of the roads, because of the great cost of transporting better materials, will have to be built of it. It appears desirable that these constructions should be made of the bowlders rather than of the bedded rocks, and that where possible the surface of the road should be covered with materials taken from the vein deposits hereafter to be described, which occur in some abundance in many parts of this field.

CONNECTICUT VALLEY.

In this section of the State the bedded rocks consist practically of three groups—shales, sandstones, and conglomerates. The shales, those of the New Red sandstone (Rhætic) group, are unfit for use on main highways. They may be made to serve as a road covering on ways which have the smallest amount of traffic. The sandstones may be dismissed as quite unserviceable. They quickly grind to powder. Except for use as foundation in telford construction, they have no possible value in road making. The conglomerates of this field, which in many

points contain very massive beds, would, in default of better material, afford tolerably good road stones. Their pebbles are prevailingly hard, having been subjected to a severe test by water action and perhaps, at an earlier stage of their history, by the ruder ice work. Owing, however, to the fact that this section of the State superabounds in good traps, decidedly the best group of rocks for use as broken stone, it is not worth while to consider further the conglomerates or other stratified rocks of the area.

WORCESTER DISTRICT.

The bedded rocks of this field, though varied in character, are prevailingly of low value for road-making use. On the eastern margin of the area, in the obscure border between this district and the shore-land field, there are some limestones, which are best exhibited in Bolton, Stowe, and Chelmsford. These limestones occupy very much less area than those in the western part of the State—they are, in fact, but detached remnants of originally extensive deposits which are probably of the same age as those above noted in the Berkshire district. Although these limestones are very crystalline, some portions of the beds which contain materials that will pass into the state of clay may have a limited value for local use in road making. In the region about Worcester, and to the southward, there are some gneissic rocks lying on the boundaries of the Carboniferous basin, which occupies the central portion of this district, that may have a value in road building, at least for the coarse layers of broken stone. The distribution of these rocks is not yet well ascertained. It is known, however, that they are most abundant and of the best quality in the portion of the district which is nearest to the Rhode Island line.

The greater portion of the Worcester district is occupied by schistose rocks of the same general character and probably of the same age as the deposits which make up so large a part of the Berkshire Hills. In the Worcester field, as in the western part of the State, it may be necessary to use the materials from these schists in road construction at places remote from the railroad, where the cost of bringing in good stone would be too great. In these cases it will be best to take selected bowlders rather than the bed-rocks. Where the latter are chosen, a search should be made for ferruginous bands, which occur plentifully in the schists of this district and are most abundant in the western portion of the field, particularly so in and about the town of Barre. Except in cases of exigency, the use of these schists can not be recommended in any part of this area. In the greater portion of the area the road construction should be effected by the use of traps brought in from the eastern and Worcester districts or by using the field stones.

COASTAL PLATEAU.

In this section of the State the bedded rocks which are in some measure fit for road building are much more abundant and in greater variety than they are in any other. They consist of quartzites, clay-

slates, gneisses, conglomerates, and certain varieties of schistose rock. Owing to the fact that this section of Massachusetts contains a large share of good trap stone, the deposits of which can be readily distributed by railways to almost every point, so that the stone will not need to be wagoned for any great distance, the use of these stratified deposits is likely to be very limited. They will, therefore, be but briefly mentioned in this report, the mention being rather in the way of warning and with a view to check the injudicious use of these varieties of stone.

The commonest and so far the most used of the stratified rocks in the coastal plateau are the clay-slates. These abound in many portions of the district, particularly in the section immediately west of Boston. They occur in considerable variety, ranging from relatively soft materials, which have been but little changed by the metamorphic agents, to those which have been greatly hardened—some, indeed, brought almost to the condition in which our quartzites occur. Occasionally, indeed, they appear to have been altered to the state of bedded felsites.

In general, it may be said that these clay stones, however much altered, are essentially unfit for use on the highways except for telford subconstruction. The material rapidly goes to pieces under the action of the wheels, and the dust has very little cementing value; it fails to bind the fragments together; it quickly blows or washes away. Yet because of a lack of understanding which may be fairly termed stupidity, a great amount of road construction has been done with this essentially worthless rock. The waste arising from its use may safely be reckoned as having amounted during the last thirty years to somewhere near a million dollars. This waste still continues, although the relative worthlessness of the clay stones as compared with the traps of the neighborhood is now well known.

Where the clay stones have, by the change-bringing action, become in part crystalline, the road-building value of the material is enhanced to the point where it might be profitable to make use of it in cases where better rock is not obtainable; still, these rocks have to be reckoned as of a distinctly low grade.

In the central portions of this field conglomerates abound. This is especially the case in the region immediately west of Boston. These conglomerates are commonly associated in beds which occupy the same formation and often alternate with the clay-slates. Where the conglomerates afford pebbles exceeding 3 inches in diameter they may be used in road making. The trouble is, however, that the pebbles are rarely large enough to afford good road-building stone when broken up in the crusher. A large portion of the product retains the original smooth surface of the pebbles, a fact which causes a failure of the binding action which is the basis of the macadam system of construction. Moreover, the pebbles, though often hard and of good binding quality when broken into bits, are mingled in their beds with a large amount of sand. In part this sandy matter goes to pieces in the crusher and is separated by the screens of the apparatus; where this occurs, the

waste of material at the breaker is likely to amount to as much as a quarter of the material quarried for use. In other cases the sandy matter remains firm enough to pass into the "grades" of stone which are to be used on the road, and if so used it is likely seriously to weaken the construction. On these accounts the conglomerates of what is commonly known as the Boston Basin are not to be commended as sources of road stone.

In the southern portion of the district, particularly in Norfolk and Bristol counties, there are extensive conglomerates of the age of the Coal Measures and of rather better quality than those which lie to the northward. The pebbles in this southern field are harder, the mass often more metamorphosed. Still, in view of the more desirable kinds of rock which exist within easy access of this portion of the field, the use of the conglomerates is not to be commended.

The gneisses and the other more or less schistose rocks of this district are in general of undesirable quality. In only one district, that including the shore towns between New Bedford Harbor and Narragansett Bay, does it seem desirable to resort to the bed-rocks of this nature as sources for road material. In the towns just noted, for the main highway between New Bedford and Fall River, the Massachusetts highway commission has, after much consideration, determined to recommend the use of a very granite-like gneiss as a source of the broken stone. This choice has been made for the reason that the field stone is in the main from the Coal Measure field which lies to the northward, and is prevailingly poor, and the cost of bringing in better rock by rail or water, supplemented by wagon transportation, would be very great. Moreover, on this line of road, ledges rising well above the way are immediately adjacent to it, and an arrangement was made with an existing electric tramway, which is to carry broken stone to within a few feet of the places where it is to be deposited on the road. Under these conditions, and with the guiding plan of adapting the materials in the best way to the economic situation, the use of this gneiss is clearly to be reckoned as advantageous.

SOUTHEASTERN DISTRICT.

In this field the deposits below those of Glacial age are essentially without value for use in road construction. Some of the clays have been made to serve in hardening roads, and the benefit which these materials afford when applied to the sand is temporarily great, but the endurance of the beneficial effects is so slight that it is not worth while to incur the cost of the work. Here and there other deposits, such as bog-iron ores, are found, as they are in other portions of the Commonwealth, which may in case of need serve to give a temporary hardness to the way.

At many points along the shore, from the northern side of Boston Harbor to Narragansett Bay, there occur beneath the tidal marshes

and the mud flats great areas which below the water level are occupied sometimes to the depth of 8 or 10 feet by beds of oyster shells. Although these shells are somewhat decayed and do not have the toughness which makes them so serviceable as a covering for highways which have to endure but a small amount of wearing, it seems likely that the cheapness with which the material can be won by dredging may in the end commend it to extensive use, particularly on private roads and on highways which, though of importance, are traversed only by light vehicles. Where the oyster beds occur the material can often be lifted by the steam dredge or the hydraulic excavator at a cost not exceeding 15 cents per ton. At anything like this price the material is worth attention, not only for use on light-traffic roads, but also for the manufacture of lime to be used in the ground state as a fertilizer. Lime prepared from this source has a considerably greater agricultural value than that which is obtained from the crystalline limestones of the Atlantic Coast, such as those which afford at Rockport, Me., the largest supply that is used in New England.

In the greater part of the swamps of New England, particularly in those which occupy the southern portion of the area, there occur considerable deposits of bog-iron ore. These vary in thickness from a few inches to 3 feet, and in character from ocherous sands to very firm deposits containing from 30 to 40 per cent of the bog iron. Wherever accessible this bog ore is likely to have value as a top covering for roads which are not to be macadamized in the strict sense of the term, or for those which are to be covered with broken stone of which the quality is defective as regards cementation value of the material. On this account it is desirable to make some statements concerning the distribution of this group of deposits, which in the last century were the basis of a considerable industry in iron production and which may now be looked to for subsidiary use in road making. As the conditions under which these bog-iron ores are produced are peculiar and throw much light on the positions in which they may be found, a brief statement as to the steps of their formation will not be out of place. All of the large amount of iron oxide contained in the swamps of the glacial belt has been formed in the manner which will now be described.

The greater part of the drift of New England is derived from rocks which contain a considerable amount of ferruginous matter. This material is particularly abundant in the crystalline deposits which abound throughout this area. Penetrating through these drift materials, the surface waters, considerably charged with carbonic acid gas derived from the decaying vegetation, take up a share of these iron oxides and bear them on toward the sea. Where the waters enter a swamp and the ferruginous matter comes in contact with the partly decayed vegetable remains, the charge of iron oxide is likely to be precipitated; owing to its weight it finds its way to the bottom of the soft marsh and there agglomerates in the form of a more or less distinct

sheet, which often takes on a curious stalactitic form. In those places where the surface water draining into a swamp passes through ordinary sand the contribution of ferruginous material is usually small, and thus the bog-iron ore never attains any considerable development. Where, however, the drainage is from a region occupied by till, partly for the reason that the water passes more slowly through beds of that nature, but mainly because the till is apt to contain a considerable amount of iron oxides, the opportunity for the growth of bog-iron ores in the neighboring swamps is likely to be great. So far as the observations of the writer have gone, these deposits are more common in the portions of the State lying to the west of the coastal plateau; they are relatively rare in a utilizable quantity in the southeastern district. Nevertheless, in Plymouth and Bristol counties deposits of this kind have been found with a thickness of 18 inches, and this without any extended search for them. Further inquiry concerning these materials is to be desired.

DIKE AND VEIN STONES.

The dike stones of this country have been found to afford the best materials for road construction, especially for use on ways which are necessarily the seat of a heavy traffic. With them may be classed the related volcanic rocks which have come forth in the form of flows and not been intruded between the walls of fissures, as in the case of true dike materials. For the purpose of this report it will not be necessary to make scientific discrimination between the many varieties of these igneous rocks; the differences between them in many cases rest upon very recondite features, such as can not well be taken into account in writings which are meant to be of general utility.

In the Berkshire district of Massachusetts, though numerous dikes occur in that field, the deposits of a kind to be useful in road making, so far as known, are all rather small, and are in positions which make them unworkable. Although a more careful study of this district may possibly reveal dike stones of value, the habit of the country is clearly against the probability of the occurrence of the deposits in utilizable quantities. In this district, however, ordinary veins, such as are deposited by the ascent of heated waters through fissures, occasionally occur, especially in the eastern portion of the field. Although no careful study has been made of these veins, some of them have been found to be large, and on account of the economic minerals which they contain have been extensively worked. Thus, in the town of Rowe, in the northern part of Franklin County, a vein of iron pyrites has been for many years the seat of considerable production, and in the town of Chester vein deposits of emery have likewise been extensively worked. In and about the town of Goshen there are extensive veins that are likely to be exploited as sources of lithia; this is contained in the mineral termed spodumene, which occurs as crystals in the deposits.

TRAP DIKE, SOMEWHAT DECAYED, SHOWING THE CONDITION OF THE WALL ON ONE SIDE; BRIGHTON, MASSACHUSETTS.

From Gardner Collection of Photographs, Lawrence Scientific School, Harvard University

The waste accumulated in working the vein deposits of the Berkshire district is likely to prove of much better quality for use on roads than the ordinary rock of the country, and in time to come it may at some points be profitably applied to the construction of local ways.

CONNECTICUT VALLEY.

In the Connecticut Valley is found the most extensively developed deposits of igneous rock having the general character of trap which exist in New England. These great accumulations abound in Massachusetts and Connecticut. They occur here and there throughout its extent from the mouth of the Deerfield River to Long Island Sound. In age and character they are the same as the traps of the Palisade district on the Hudson and of New Jersey. Their fitness for road building has been very extensively tested and amply proved. As regards their origin, these traps are to a great extent true lava-flows which were poured out upon the floor of the shallow sea, the sheets sometimes attaining a thickness of 100 feet or more. Although in all cases they were buried beneath subsequently accumulated strata, they have, by faulting, uptilting, and wearing away of the covering, been not only disclosed but placed in convenient conditions for working.

The condition of the traps of the Connecticut Valley is such that not only is that section of Massachusetts and Connecticut in which they lie so well provided with good road material that other sources of supply need little consideration, but the greater portion of the country on either side of the Connecticut River within a distance of 100 miles is, where near railways, able to look to this store of natural road material for better and, in a long view, a cheaper source of road stone than the local rocks afford. With the progressive extension of steam and electric railways it is not unlikely that the use of the local road-building stones in the Berkshire and Worcester districts will be abandoned, except in the case of those towns which are remote from such means of transportation.

WORCESTER DISTRICT.

The general resemblance of the Worcester district to that of the Berkshire Hills, which has already been noted as regards the bed-rocks, is found also in the relative absence of igneous materials in this area. A tolerably careful search has failed to show the existence of any utilizable dike stones or lava-sheets in this portion of the State. The harder vein stones are equally rare. No deposits of this nature have been found that are likely to prove sufficiently valuable in road making to deserve notice.

COASTAL PLATEAU.

In this district the igneous rocks exist in greater variety than in any other portion of the Commonwealth. Such great lava-flows as exist in the Connecticut Valley are lacking here, but in their place there is

a great array of injected and ejected rocks which have come into their position in a heated state.

First among the igneous rocks of this district, as regards the quantity of the material, we may reckon the granitic masses, such as those which occur in the Quincy and neighboring fields at Cape Ann and in a local and less extensive way in other portions of the area. These granitic masses have broken through, displaced, and in part probably flowed over the older rocks throughout regions which aggregate some hundreds of square miles in area. They evidently came into their position not on the surface but at a great depth within the crust of the earth. From the point of view of road making, the granitic rocks, though they vary somewhat in quality, are generally of inferior grade. They usually contain a large amount of quartz, and their very crystalline structure causes them readily to go to pieces when placed on the roads. Where, as is sometimes the case, there is a considerable proportion of mica in these rocks, the destruction is yet more rapid. Thus, while the granites of this district are commendable on account of their hardness and their fair cementing properties, their brittleness and the crystalline nature of the fines which they produce when ground make them unfit for use on roads where better materials can be obtained.

In certain parts of this district, particularly along the northern shores of Boston Harbor and Massachusetts Bay, there occur extensive deposits of what are termed felsite-porphyries, which seem to have been formed somewhat after the manner of lavas, but probably as horizontal flows within the rocks themselves. The igneous rocks of this group are fairly serviceable in road making. They are rather brittle, and the binding power of their powder is not great. They would be valuable in many parts of the Worcester district, but in this, which abounds in good road materials, they are not to be commended.

The ordinary dike stones of eastern Massachusetts are abundant, and generally of an excellent quality. It is to be noted that these dikes often appear to be much decayed on and near the surface, as is shown in Pl. XXIII. Rarely, however, does this decay extend to a considerable depth, so as to limit the value of the stone for road use The number of the deposits is surprisingly great. There are a few parts of the world where, over equally extensive fields, the number of fissures filled with these originally molten rocks is as great. Thus, on the island of Cape Ann, an enumeration of the dikes measured along the narrow strip of the coast-line, where they are exposed to view, gave a total of about four hundred of these fissures. Within the area of the coastal plateau the number of the separate crevices is probably to be reckoned by tens of thousands. Their general aspect when exposed in quarrying is approximately indicated in Pl. XXIV, in which are depicted a trap sheet which has been forced between layers of slate, and an ordinary fissure dike which intersects the strata.

The dikes of this district increase in number in a progressive manner from its western border toward the shore-line. They are more common

INTRUSIVE SHEET OF TRAP CUT BY DIABASE DIKE; SOMERVILLE, MASSACHUSETTS.

From Gardner Collection of Photographs, Lawrence Scientific School, Harvard University

in the originally deep-seated rocks, such as the granites, than in the newer formations, such as the Carboniferous. The evidence goes to show that their formation was attendant on the development of much volcanic activity in the regions lying immediately to the east of the Massachusetts shore and southward of the coast of Maine. In connection with these dikes, on the coast-line at Cohasset and elsewhere, there are deposits of volcanic ash, which are doubtless more centrally developed beneath the neighboring sea. At certain points on Cape Cod the drift is largely made up of dike stones and other igneous rocks, which serves to show the great extent of these submarine volcanic beds.

The greater part of the dikes of eastern Massachusetts are narrow, few of them exceeding 20 feet in width. In order that a deposit of this nature may afford a valuable quarry for road-building materials, it is necessary that it be large. In general, it may be assumed that a fissure should have a width of not less than 50 feet and a length of several hundred, and that it must lie in a position, as in the escarpment of a hill, which will permit the development of working faces having a height of 20 feet or more. So far as observations go, the number of dikes which afford these conditions in eastern Massachusetts does not exceed a dozen. Of these, two, one in Salem and another in Waltham, have already been extensively used as sources of road-building stone. There are others in the region about Newburyport, their nature having been disclosed in the search for silver-bearing ores which was made in that section about a quarter of a century ago. Yet another lies on Houghs Neck, Quincy, on the shores of Boston Harbor, in an advantageous position for working.

Just beyond the boundaries of Massachusetts, in Rhode Island, there are two admirably placed deposits of dike stones, which are mentioned here for the reason that, while they are not within the boundaries of the State, they are advantageously situated for supplying the Worcester district, where, as before remarked, there is a lack of good road materials. One of these is a true dike trap, which is situated on the left-hand bank of the Blackstone River, just above Woonsocket, R. I.; the other is the well-known deposit of magnetic iron ore in the town of Cumberland, R. I. This mass contains in the aggregate several million tons of a particularly hard and tough rock which appears to be very well adapted for road making. It is true that the powder of the material has only a moderate cementing power, but the dust is so heavy that it is not likely to be removed from the road by the action of water or of air. Unfortunately both of the localities above mentioned are somewhat inconveniently placed; that on the banks of the Blackstone River may have to be approached by a bridge across that stream or by a spur from the New York and New England Railroad, while to obtain access to the Iron Hill deposit, in Cumberland, it will be necessary to construct a branch railway for the distance of about 1½ miles.

In the district lying between Canton Junction and Wrentham, in Bristol County, there are numerous extensive extrusions of trappean materials, or those which for the present purpose may be thus classed, that may afford a valuable source of supply of road-building stones for the county in which it lies and for the neighboring portions of Massachusetts and Rhode Island. Here also, unfortunately, a mile or two of railway will have to be constructed in order to gain access to the field. There are a number of other promising localities where the dike masses appear to exist under conditions which are favorable for production, but these conditions are not as yet well enough known to enable the writer to commend them to those who are engaged in the search for good localities in which to establish crushers for the immediate supply of the general market.

SUMMARY CONCERNING ROAD-BUILDING STONES.

The foregoing account of the road-building stones of Massachusetts serves to show that this State is, on the whole, very well placed for access to good materials for highway construction. It is, moreover, perhaps the best field in this country in which to institute an extended system of experiments intended to determine the relative value of these materials and the proper method in which to use them in diverse conditions and combinations. In this State, though it has an area of only 8,200 miles, there are at the present time, exclusive of city streets, about 10,000 miles of way which should be macadamized, and which will, presumably, be thus constructed before the middle of the next century. The actual cost of this work for the stone alone will probably be between $50,000,000 and $60,000,000, and the annual replacement of the macadam materials will probably involve a cost not far from $3,000,000. It is thus evident that the expense of the road work in this State is to be a considerable tax upon the earning powers of the people, though the profit will doubtless very much exceed the cost of the undertaking. In this State, as in the other parts of the country, it is clearly a sound policy to make the considerable saving which may be won through a thorough-going study of the nature and methods of use of every variety of stone that is likely to be drawn upon for the needs of road building.

ON THE TOPOGRAPHIC CONDITIONS OF MASSACHUSETTS AS AFFECTING ROAD BUILDING.

It seems proper to supplement the foregoing account of the highway materials of Massachusetts by a statement, necessarily brief, as to the form of the surface, so far as the form affects the construction of the roads.

Although the area of Massachusetts is relatively small, and the relief in maximum height not great, the surface presents what is perhaps a greater combination of difficulties in the construction of roads of proper grade than exists in any other equally extensive field of this country

outside of the Cordilleran region. In the Berkshire district we find an elevated field, having somewhat the aspect of a table-land, intersected by deep valleys. The same deeply incised topography is to a considerable extent presented in the Worcester district, and traces of it are to be found in the coastal plateau. Thus the grades which are due to the understructure of the country give rise to many difficult problems, which have to be met by those who plan public ways. The principal difficulty, however, that which is due to the topography of the country, is attributable to the very irregular character of the drift accumulations. The aggregate slope imposed upon the highways of the State by these irregularities, though none of the slopes are of great altitude, is probably much greater than that due to the more extensive elevation of the mountainous areas.

The effect of the drift accumulations, owing to the extreme irregularity of their forms, is to bring about the existence of many hundred lakes of considerable size, and a yet greater number of swamps which originally had a lacustrine character. The result is that in planning the original highways of the State quite without a map the roadways were laid out in an exceedingly clumsy way. Here and there we may detect in the choice of the position of the ways evidence that they were planned by persons of unusual natural ability as engineers; but at least nine-tenths of the road mileage of Massachusetts has been located without a proper study of the country, and by men who had no sense of the gravity of the task which they undertook. Although the tax which arises from the inadequate character of the roadbeds of the Commonwealth is very great, it seems to the writer that the evils which are due to defects of location are yet more serious, and, of course, are likely to be much more permanent.

The only way to provide against the extension of this evil, in case the road should have to be reconstructed, and for its proper remedy by the relocation of ways, is through a provision in the form of high-grade maps which shall display the topography of the country, in both its horizontal and its vertical elements, in a manner sufficiently accurate for the roadmaker's use. The map of the Commonwealth made a decade ago by combination of the work of the United States Geological Survey and that of the topographical survey of the Commonwealth will, to a certain extent, serve this need. By careful use of these charts it is possible, as experience shows, to make a preliminary project concerning a road in a tolerably effective manner. But to do the work thoroughly this system of mapping should be completed in such shape as to give sheets which, at least in the office form, will be on the scale of 1 foot to the mile. These sheets should be colored to indicate both the nature of the soil and surface deposits and that of the underlying rocks.

Although it might not be considered advisable to undertake the preparation of maps on this scale with reference alone to the construction of roads, the task is warranted by the fact that no district which is so

densely inhabited as is this State can organize its system of land taxation, of water supplies, of drainage, etc., without large-scale maps. Thus, while such charts are demanded with reference to transportation routes, they are necessary for many other branches of public service. It may, moreover, be said that the enlightened use of the road materials demands that maps be prepared on a scale sufficiently large to indicate the sources and quantities of these materials. Proper indications for guiding this work can not be given on the small-scale maps which now exist.

THE BRICK-MAKING CLAYS OF MASSACHUSETTS.

In the modern development of carriage-ways there has come about a considerable extension in the use of the method of paving with burnt brick. This method originated in Holland, and it has been maintained in that part of Europe for some centuries. It has been in a very limited way applied to the roads of this country within the last twenty years, but it has met with such approval that the clays of any district which are suitable for making paving brick of a quality which may serve for wheel-ways must be counted as among its important highway resources. Therefore, though as yet no such paving bricks have been made in Massachusetts, it seems fit that an account of the deposits which may be made to serve this purpose should be given in this report.

So far as the writer has been able to determine by an examination of the clays which are useful in making paving brick suitable to be placed on highways, there is demanded material which combines silica and alumina with the minimum of potash, soda, or other substances which may be calculated to make the brick flux or attain the state of glass when heated in the process of burning. At the same time it is necessary that at a given high temperature a slight liquefaction or softening of the quartz should take place, in order that the particles may become welded together. So far as experiments have gone, it has not as yet proved possible to determine by analysis, or even by laboratory tests in burning, whether a given clay will prove to be suitable for the use which we are considering, and this for the reason that much depends on the mechanical conditions of the mass. Among these conditions we may note the necessity of having the fragments which are to be bound together individually hard and rather coarse. To this requirement is due the fact that it is in general most profitable to make the clay from which the bricks are to be produced by grinding up somewhat hard and coarse-grained shales, rather than to use the ordinary finely divided clays.

Among the deposits which exist in Massachusetts of a nature to warrant experiments with a view to producing high-grade paving brick, we may note the following: In the Berkshire district, especially in the region in and about the town of Blandford, there are extensive deposits of clays, the finer of which, under the name of kaolin, are to a consid-

erable extent carried to distant markets. These clays have properties which will make them, when mingled in the pug mill with ground-up fragments of quartzite, a possible resource in road-brick making. The finer variations may prove too valuable for such use, but the coarser, which are not suitable for exportation, might be made to serve in the manner above indicated.

In Bristol County the Coal Measures, which are there extensively developed, afford many beds of indurated shale, which, when ground and perhaps mixed in some measure with clays from deposits of the Glacial age, will be likely to yield high-grade paving brick. In this connection it may be noted that some of the most successful establishments engaged in the manufacture of such brick in Illinois obtain the material from deposits of Carboniferous age. It may also be said that the coal beds of the Narragansett basin, which have as yet been but little worked, bid fair to afford a tolerable material for burning bricks. It is not likely that these coals could be used for that purpose in their raw state, but if converted into water gas they would probably serve quite as well as does petroleum for use in the kilns.

On the island of Marthas Vineyard there exists an area about 50 square miles in extent underlain by Cretaceous and Tertiary clays and sands, where almost any desired quality of material for brick making can be obtained by mixing the product of different beds. In the present conditions of this island the clay deposits, though near the sea, are not approachable through good harbors. At the cost of a few thousand dollars, however, probably for less than $10,000, a very good port for vessels drawing not more than 10 feet of water could be made by cutting through the beach which separates Menemsha Pond from Vineyard Sound. It is likely that if such provision for transportation is ever made the clays of this district will come to be used for the production of paving brick.

The glacial clays of Massachusetts are extensively distributed, and frequently occur under conditions which make it seem likely that they may serve, when mixed with other materials, for the manufacture of paving brick. In the Berkshire district these clays of good quality are rarer than elsewhere in the State. They are, moreover, rather too fusible for this use, owing to the fact that the schists afford minerals that are rich in lime and soda, which give the resulting clays a tendency readily to pass into the state of glass.

The river clays of the Connecticut Valley appear to be promising for experiments in the production of paving brick, but so far as is known to the writer there are no conveniently accessible deposits of the hard rocks which are suitable to be used in the mixture, unless the trap stones should prove fit for such use.

In the Worcester district the clays are prevailingly too fusible for use in any mixtures where the object is to produce a hard burning of the material with only a semiliquefaction. So far as is known to the writer,

there are no deposits in this section of the State which are worth attention from those who are seeking brick-making clays.

In the region of the coastal plateau the glacial clays are relatively abundant and of varied quality. The experience of the brick-makers shows that in general the hard burning can be induced without excessive production of glass in the bricks, and though in all cases these clays will need to be mixed with some form of ground hard rock, there is reason to suppose that with such treatment they will serve the end which is here in view. The brick clays of this district, or at least all of those of this nature which are worth considering, are found in the lowlands of the river valleys, or adjacent to the seashore. They are well developed in the Merrimac Valley below Lowell, in that of the Charles and the Mystic, and they occur plentifully in the eastern portion of Bristol County and in the valley of the Taunton River. Taken together, the area of deposits of this nature which is accessible for working probably exceeds 25 square miles, though throughout the greater portion of this extent the layers of clay are covered by a coating of sand having a depth of from 1 to 10 feet.

Among the varied rocks of this district which may be used for mingling with the glacial clay to give it the texture that appears to be necessary for making paving brick, we may note the several species of stone. Perhaps the best suited to this end are the felsites and porphyries, and along with these may be classed the darker-colored dike stones, which are used as road material. Of these the felsites are most easily ground. Some of the very indurated felsites and quartzites may be made to serve the same purpose. The granitic rocks, where they are not micaceous, are likely also to prove useful in supplying the necessary kind of admixing material.

It should be clearly understood that the statements here made concerning the possible resources for the production of paving brick are mere suggestions, and are not to be taken as the basis of any economic work. Those who intend to inquire further into the matter should submit the materials to careful trial in a somewhat extensive way. Owing to the fact that the demand for paving brick promises to be quite large in the near future, these trials may be recommended, especially as, in the present condition of the market, the nearest source of supply of brick of high grade is in Illinois. If, by the proper treatment of the materials found in Massachusetts, bricks of equally good quality can be produced at anything like the cost at which they are made in the Mississippi Valley, the undertaking should prove remunerative.

ROAD-MAKING GRAVELS.

It has long been the custom in Massachusetts, as elsewhere within the glaciated district of this country, to cover highways with a coating of gravel, the layer being put on to the depth of from 6 inches to 1 foot. At the present time the greater part of the length of the fairly well-

made highways in this State have been constructed in this manner. The success of this method has been extremely varying. In many cases the gravel thus used has been found to compact after the manner of macadam rock, the road remaining smooth and tolerably enduring when subjected to a moderate amount of traffic. In other instances—much the greater portion of the whole—the material, even when brought into position by the use of the roller and well underdrained, has failed to unite into a solid mass and has quickly been reduced to an incoherent state.

The experience which has been gained in Massachusetts is to the effect that, save under rarely occurring conditions, the use of gravel in the construction of roads is not to be recommended, and this for the reason that the rate of wear of the material is in general so rapid that the cost of repairs, when capitalized, makes highways of this description more expensive than are those which are constructed of macadam. On this account it does not seem desirable to give any extensive description of the road-making gravels of this area. The statements made below are intended for the guidance of those roadmasters who may be inclined to maintain a method of road building which in the present condition of the art can not be deemed sound practice.

The road-making gravels of Massachusetts which can be trusted to form a tolerably firm bed depend for their satisfactory qualities on one or more of the following conditions: They are composed of pebbles derived from rocks which have a high cementation value; they contain a considerable admixture of iron oxides; or they have, on account of their deeply covered position, remained in the condition in which they were immediately after their formation. In general, it may be said that the first-named class of road making gravels is the most serviceable, the deposits belonging to the other groups being of relatively rare occurrence.

As regards the distribution of the road-making gravels, it may be said that no deposits of good quality are as yet known in the portion of the State lying to the west of the eastern margin of Worcester County. In the Berkshire district the larger valleys, particularly west of the Deerfield River, contain deposits which have a certain cementation value, this feature being due to the fact that a considerable proportion of the pebbles have been derived from the harder rocks of Vermont. As a whole, it may be said that these gravels are of an inferior quality.

In the region east of Worcester County, owing in the main to the large amount of trappean deposits and to the greater survival of the pebbles derived from these rocks, the gravels are, from the point of view of the road-maker, at their best. In the county of Essex deposits of this nature occasionally afford materials which can be used, after careful screening, with almost the same advantage that would be obtained from the ordinary grades of macadam rock.

In what is commonly known as the Cape district, i. e., the section lying to the south and east of a line drawn from Plymouth to Marion,

road-making gravels appear to be entirely wanting. The pebbly beds are composed mainly of quartz, and the fragments of other rocks are commonly so much decayed that they are unfit to serve as a binding material to unite the other portions of the mass.

It seems not unlikely that the deposits of gravel in Massachusetts may in many instances prove useful as foundation materials on which is to be placed a superstructure of macadam rock. By this method of construction it is possible somewhat to reduce the total thickness of the macadam layer. As yet careful experiments looking toward this form of construction are lacking.

STATISTICS CONCERNING THE RESISTANCES TO WEAR OF ROAD-BUILDING STONES.

The following tables represent the results of the tests which have been applied to samples of road-building stones. These results were obtained by Mr. L. W. Page, geologist of the Massachusetts highway commission, by the method described on page 286 of this report.

ABRASION TESTS OF ROAD-BUILDING STONES.

[The first Arabic numeral following the name of the locality indicates the sheet of the U. S. Geological Survey map of Massachusetts; the Roman number, one of the nine sections into which the map is divided; the number and letter in curves, the exact location whence the specimen came. In this last method of indicating, each section of the map is divided vertically into twenty-six divisions, designated by the letters of the alphabet, and horizontally into thirty-four divisions, which are indicated by numbers. Although it has proved impracticable to have a detailed map of Massachusetts accompany this report, it has seemed well to retain these note-book indications, for the reason that they afford a tolerably accurate and quite permanent record as to the site of the specimens which have been tested.]

No. 1.—Locality of stone: Lee, Berkshire County, Mass. 2, IX (15—Z). Name of stone: Marble. Coefficient of wear, 2.85.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,131.82	153.81	7.01	0.77	5.54	10.63	92.14	584.63	13.65	700.72
Ounces	145.44	5.41	.25	.03	.19	.37	3.24	20.58	.48	24.67
Per cent	82.64	3.08	.14	.02	.11	.21	1.84	11.69	.27	14.01

REMARKS.—Although the binding power of this stone is high, it is so soft and has such a tendency to crumble that it would be worthless as a road metal. It might possibly be used to advantage as a binder in surfacing roads. Selected specimens could be obtained at the same quarry which would stand a higher test than this.

No. 2.—Locality of stone: Lenox, Berkshire County, Mass. 2, VII (24—Q). Name of stone: Mica schist. Coefficient of wear, 8.04.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,700	42.97	3.94	0.38	2.31	5.80	30.97	205.52	8.11	248.92
Ounces	165.44	1.51	.14	.01	.08	.20	1.09	7.23	.28	8.76
Per cent	94	.86	.08	.01	.04	.11	.61	4.11	.16	4.98

REMARKS.—This rock is very heterogeneous; it contains a great deal of quartz and mica. Its only value as a road metal is its resistance to decay. It would probably do well as a foundation material for roads.

Abrasion tests of road-building stones—Continued.

No. 3.—Locality of stone: Pittsfield, Berkshire County, Mass. 2, VII (28—D). Name of stone: Limestone. Coefficient of wear, 9.38.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,695.74	82.83	1.65	2.55	13.95	7.82	20.90	166.28	8.28	213.15
Ounces...	165.29	2.92	.06	.09	.49	.28	.74	5.85	.29	7.50
Per cent.....	93.91	1.66	.03	.05	.28	.16	.42	3.33	.17	4.26

REMARKS.—This stone is of a light-gray color, and rather hard for limestone. It would undoubtedly make a good road if not subjected to heavy traffic.

No. 4—Locality of stone: Duxbury, Plymouth County, Mass. 44, III (26—L). Name of stone: Hornblende-granitite. Coefficient of wear, 13.46.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,777.27	65.19	0.21	0.23	3.99	4.20	17.07	122.84	9.00	148.54
Ounces...	168.16	2.29	.01	.01	.14	.15	.60	4.32	.32	5.23
Per cent.....	95.54	1.62	.004	.004	.07	.08	.34	2.46	18	2.97

REMARKS.—This rock gives a very high coefficient for one of its class. It was considerably weathered, which may possibly account for it It is difficult to say just what its results on a road would be.

No. 5.—Locality of stone: Waltham, Middlesex County, Mass. 26, VIII (23—V). Name of stone: Hornblende-granitite. Coefficient of wear, 12.16.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,789.96	33.52	0.42	0.54	6.55	5.25	17.02	134.70	12.04	164.48
Ounces...	168.61	1.18	.01	.02	.23	.18	.60	4.74	.42	5.79
Per cent.....	95.80	.67	.01	.01	.13	.11	.34	2.69	.24	3.29

REMARKS.—This rock has been used a great deal in road making, and its results have been very good for a rock of its class.

No. 6.—Locality of stone: Salem, Essex County, Mass. 37, VI (31—F). Name of stone: Augite-diorite. Coefficient of wear, 15.55

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams....	4,840.91	22.32	0.39	0.38	2.74	2.94	11.64	110.51	8.17	128.60
Ounces...	170.40	.79	.01	.01	.10	.10	.41	3.89	.29	4.53
Per cent.....	96.82	.40	.01	.01	.05	.06	.20	2.21	.16	2.57

REMARKS.—This stone has been used very extensively throughout eastern Massachusetts, and its results have been most satisfactory.

Abrasion tests of road-building stones—Continued.

No. 7.—Locality of stone: Tomkins Cove, N. Y. Name of stone: Limestone. Coefficient of wear, 6.31.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,613.64	68.35	0.85	2.20	21.20	9.30	32.40	251.16	.90	317.11
Ounces	162.40	2.41	.03	.08	.74	.33	1.14	8.84	.03	11.16
Per cent	92.27	1.37	.02	.05	.42	.19	.65	5.02	.02	6.34

REMARKS.—This stone would make a good binder for surfacing a road.

No. 8.—Locality of stone: Somerville, Middlesex County, Mass. 31, V (7—M). Name of stone: Slate (probably Cambrian). Coefficient of wear, 8.48.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,719.13	29.93	0.74	2.54	19.67	10.70	31.40	170.75	15.14	235.80
Ounces	166.11	1.05	.03	.09	.69	.38	1.10	5.98	.53	8.15
Per cent	94.38	.60	.01	.05	.39	.21	.63	3.41	.30	4.72

REMARKS.—This stone has been used for some time in road making. Its results are very poor; it soon grinds to powder, and makes a great deal of mud and dust.

No. 9.—Locality of stone: Lee, Berkshire County, Mass. Name of stone: Quartzite. Coefficient of wear, 11.65.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,773.84	47.75	0.32	0.14	1.34	2.96	19.45	147.46	6.74	171.67
Ounces	168.04	1.68	.01	.005	.05	.10	.68	5.19	.24	6.04
Per cent	95.48	.95	.01	.003	.03	.06	.39	2.95	.13	3.43

REMARKS.—This stone, though extremely hard, has no binding power or toughness. It would probably not be very satisfactory except in the foundation of a road.

No. 10.—Locality of stone: Northampton, Hampshire County, Mass. Name of stone: Hornblende-granitite. Coefficient of wear, 10.69.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,771.06	34.21	0.28	0.96	6.82	5.75	18.60	154.71	7.61	187.12
Ounces	167.94	1.20	.01	.03	.24	.20	.65	5.45	.27	6.59
Per cent	95.42	.68	.01	.02	.14	.11	.37	3.10	.15	3.74

REMARKS.—This stone would give only fair results, as it contains a high per cent of quartz, which renders it very brittle.

Abrasion tests of road-building stones—Continued.

No. 11.—Locality of stone: North Attleboro, Bristol County, Mass. Name of stone: Field stone (erratics). Coefficient of wear, 9.09.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,756.88	15.80	1.78	23.37	33.51	11.80	40.35	109.28	7.23	220.09
Ounces	167.44	.56	.06	.82	1.18	.42	1.42	3.85	.25	7.75
Per cent	95.14	.32	.04	.47	.67	.24	.81	2.19	.14	4.40

REMARKS.—This stone varies so much in character that its results on the road would be only fair. It is not weathered so much as field stone generally is, which may account for its rather high coefficient.

No. 12.—Locality of stone: Whitman, Plymouth County, Mass. Name of stone: Field stone (erratics). Coefficient of wear, 5.93.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,482.51	175.86	0.87	28.97	17.37	13.45	42.99	233.76	4.22	337.41
Ounces	157.78	6.19	.03	1.02	.61	.47	1.51	8.23	.15	11.88
Per cent	89.65	3.52	.02	.58	.35	.27	.86	4.68	.08	6.75

REMARKS.—This stone varies so much in character and is weathered to such an extent that it would be of little value as a road metal.

No. 13.—Locality of stone: Mattapoisett, Plymouth County, Mass. Name of stone: Field stone (erratics). Coefficient of wear, 8.78.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,699.42	70.60	0.47	11.27	23.10	14.47	26.40	151.48	2.79	227.69
Ounces	165.42	2.49	.02	.40	.81	.51	.93	5.33	.10	8.01
Per cent	93.99	1.41	.01	.23	.46	.29	.53	3.03	.06	4.55

REMARKS.—This stone is somewhat weathered and varies much in character.

No. 14.—Locality of stone: Everett, Middlesex County, Mass. 31. VIII (6—N). Name of stone: Olivine-diabase. Coefficient of wear, 13.87.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,845.83	5.24	0.22	25.35	23.06	7.45	16.99	71.07	4.79	144.14
Ounces	170.57	.18	.01	.89	.81	.26	.60	2.50	.17	5.07
Per cent	96.92	.10	.004	.51	.46	.15	.34	1.42	.10	2.88

REMARKS.—This rock is rather coarse grained, which probably accounts for the rather low coefficient for a rock of its kind. It has been used in road making, and its results are fairly good.

Abrasion tests of road-building stones—Continued.

No. 15.—Locality of stone: Revere, Suffolk County, Mass. 31, VII (26—T). Name of stone: Felsite. Coefficient of wear, 13.21.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,775.59	68.65	0.53	1.37	4.70	7.66	22.26	114.94	4.30	151.46
Ounces	168.10	2.42	.02	.05	.17	.27	.78	4.05	.15	5.33
Per cent	95.51	1.37	.01	.03	.09	.15	.45	2.30	.09	3.03

REMARKS.—This rock is extremely hard, but very brittle. It is probably too brittle to give very good results.

No. 16.—Locality of stone: West Springfield, Hampden County, Mass. 12, II (25—R). Name of stone: Olivine-diabase. Coefficient of wear, 15.60.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,840.26	26.61	0.65	0.98	3.27	2.77	8.98	111.55	4.93	128.20
Ounces	170.38	.94	.02	.03	.12	.10	.32	3.93	.17	4.49
Per cent	96.80	.53	.01	.02	.07	.06	.18	2.23	.10	2.56

REMARKS.—This stone has been used in road making, and its results have been very satisfactory.

No. 17.—Locality of stone: Meriden, Conn. Name of stone: Augite-diabase. Coefficient of wear, 12.50.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,803.53	31.92	0.63	1.26	4.13	4.37	9.70	139.87	4.59	159.96
Ounces	169.08	1.12	.02	.04	.15	.15	.34	4.92	.16	5.63
Per cent	96.07	.64	.01	.03	.08	.09	.19	2.80	.09	3.20

REMARKS.—This rock has been used extensively in Connecticut for road building, and its results are said to be good. The specimen received of this stone was a poor one.

No. 18.—Locality of stone: Holden, Worcester County, Mass. Name of stone: Field stone (erratics). Coefficient of wear, 6.58.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,658.49	30.88	0.12	0.23	2.34	6.00	31.27	263.95	6.72	303.91
Ounces	163.98	1.09	.004	.01	.08	.21	1.10	9.29	.24	10.70
Per cent	93.17	.62	.002	.004	.05	.12	.63	5.28	.13	6.08

REMARKS.—There were several varieties of stone in this test, all of which were weathered considerably. Only a poor result can be expected from this stone.

Abrasion tests of road-building stones—Continued.

No. 19.—Locality of stone: Newton, Middlesex County, Mass. 31, II (32—L). Name of stone: Trachyte. Coefficient of wear, 20.79.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm or $\frac{1}{100}$ in.		
Weight:										
Grams	4,890.52	12.20	0.49	0.50	4.18	4.01	12.52	74.49	1.09	96.19
Ounces	172.15	.43	.02	.02	.15	.14	.44	2.62	.04	3.39
Per cent	97.81	.24	.01	.01	.08	.08	.25	1.49	.02	1.92

REMARKS.—This stone is exceedingly hard and tough. Its coefficient shows it to be of an excellent quality. It has been used in road making, and its results are excellent.

No. 20.—Locality of stone: Newton, Middlesex County, Mass. 31, III (1—V). Name of stone: Conglomerate. Coefficient of wear, 8.67.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in		
Weight:										
Grams	4,657.84	106.80	0.46	0.85	12.65	10.20	32.27	174.21	4.72	230.64
Ounces	163.96	3.76	.02	.03	.45	.36	1.14	6.13	.17	8.12
Per cent	93.16	2.14	.01	.02	.25	.20	.65	3.48	.09	4.61

REMARKS.—The stone used in this test was considerably weathered; so much so, that the pebbles had a tendency to separate from the matrix. This stone has been used in road making, and its results are only fair.

No. 21.—Locality of stone: Brookline, Norfolk County, Mass. 31, VI (5—B). Name of stone: Hornblende-diorite. Coefficient of wear, 11.40.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in		
Weight:										
Grams	4,808.26	10.78	1.05	1.40	6.92	7.41	20.85	137.75	5.58	175.38
Ounces	169.25	.38	.04	.05	.24	.26	.73	4.85	.20	6.17
Per cent	96.17	.22	.02	.03	.14	.15	.42	2.75	.11	3.51

REMARKS.—The stone used in this test was very much weathered. It has a high cementing value, and is quite hard, and would undoubtedly make an excellent road material.

No. 22.—Locality of stone: Quincy, Norfolk County, Mass. 32, VII (3—P). Name of stone: Hornblende-granitite. Coefficient of wear, 10.16.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in		
Weight:										
Grams	4,735.37	63.10	2.56	3.60	31.70	10.19	26.36	122.39	4.73	196.80
Ounces	166.69	2.22	.09	.13	1.12	.36	.93	4.31	.17	6.93
Per cent	94.71	1.26	.05	.07	.63	.20	.53	2.45	.09	3.94

REMARKS.—This stone contains a high per cent of quartz, which renders it very brittle, too much so for a good road material.

Abrasive tests of road-building stones—Continued.

No. 23.—Locality of stone: Nantucket, Nantucket County, Mass. Name of stone: Field stone (erratics). Coefficient of wear [illegible].

	Size of mesh.								Loss.	Under [illegible] in.
	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.		
Weight.										
Grams	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ounces	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Per cent	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

REMARKS.—Consists chiefly of a variety of granites in various stages of decomposition. Its coefficient is rather high for field stone, and fair results may be expected in a road subjected to light teaming.

No. 24.—Locality of stone: Quincy, Norfolk County, Mass. [illegible]. Name of stone: Diabase. Coefficient of wear [illegible].

	Size of mesh.								Loss.	Under [illegible] in.
	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.		
Weight.										
Grams	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ounces	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Per cent	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

REMARKS.—This stone is very hard and tough, and will undoubtedly make a good road metal.

No. 25.—Locality of stone: Somerville, Middlesex County, Mass. [illegible]. Name of stone: Diabase. Coefficient of wear [illegible].

	Size of mesh.								Loss.	Under [illegible] in.
	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.		
Weight.										
Grams	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ounces	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Per cent	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

REMARKS.—This stone has considerable binding power, but it is very coarse grained and has a tendency to crumble. It would not make a good road metal.

No. 26.—Locality of stone: Medford, Middlesex County, Mass. [illegible]. Name of stone: Diabase. Coefficient of wear [illegible].

	Size of mesh.								Loss.	Under [illegible] in.
	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.	[illegible] cm. or [illegible] in.		
Weight.										
Grams	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ounces	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Per cent	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

REMARKS.—This rock has been used as a road metal, and very good results have been obtained.

Abrasion tests of road-building stones—Continued.

No. 27.—Locality of stone: Lynn, Essex County, Mass. [illegible] Name of stone: Diabase. Coefficient of wear: [illegible]

	Size of mesh.								Loss.	Under [illegible] in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or [illegible] in.	0.13 cm. or [illegible] in.	0.064 cm. or [illegible] in.	0.042 cm. or [illegible] in.	0.031 cm. or [illegible] in.	0.025 cm. or [illegible] in.		
Weight:										
Grams ...	4,[illegible]	10.72	0.14	[illegible]	[illegible]	2.42	8.39	[illegible]	[illegible]	[illegible]
Ounces ...	171.94	.38	.005	.01	.10	[illegible]	.30	[illegible]	.12	[illegible]
Per cent ...	97.70	.21	[illegible]	[illegible]	[illegible]	.05	[illegible]	1.74	.07	[illegible]

REMARKS.—This stone is very hard and tough and will undoubtedly make an excellent road metal.

No. 28.—Locality of stone: Lynn, Essex County, Mass. [illegible] Name of stone: Diabase. Coefficient of wear: [illegible]

	Size of mesh.								Loss.	Under [illegible] in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or [illegible] in.	0.13 cm. or [illegible] in.	0.064 cm. or [illegible] in.	0.042 cm. or [illegible] in.	0.031 cm. or [illegible] in.	0.025 cm. or [illegible] in.		
Weight:										
Grams....	4,[illegible]	1.92	0.14	0.91	[illegible]	2.42	[illegible]	[illegible]	[illegible]	[illegible]
Ounces ...	172.34	.07	.005	.03	.09	[illegible]	[illegible]	2.92	.13	[illegible]
Per cent.....	97.92	.04	.003	.02	[illegible]	[illegible]	[illegible]	1.66	[illegible]	[illegible]

REMARKS.—This stone is exceedingly hard and tough and will beyond doubt make an excellent road metal.

No. 29.—Locality of stone: Saugus, Essex County, Mass. [illegible] Name of stone: Diabase. Coefficient of wear: 16.08.

	Size of mesh.								Loss.	Under [illegible] in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or [illegible] in.	0.13 cm. or [illegible] in.	0.064 cm. or [illegible] in.	0.042 cm. or [illegible] in.	0.031 cm. or [illegible] in.	0.025 cm. or [illegible] in.		
Weight:										
Grams....	4,[illegible]	3.93	[illegible]	[illegible]	[illegible]	2.65	[illegible]	[illegible]	[illegible]	[illegible]
Ounces ...	171.43	.14	.01	.01	.12	.09	[illegible]	3.71	[illegible]	[illegible]
Per cent.....	97.41	.08	.01	.01	.07	[illegible]	.24	[illegible]	[illegible]	[illegible]

REMARKS.—Very good results should be expected from this stone.

No. 30.—Locality of stone: Brookline, Norfolk County, Mass. [illegible] Name of stone: Olivine-diabase. Coefficient of wear: 14.71.

	Size of mesh.								Loss.	Under [illegible] in.
	6.31 cm. or 2½ in.	3.18 cm. or 1¼ in.	0.16 cm. or [illegible] in.	0.13 cm. or [illegible] in.	0.064 cm. or [illegible] in.	0.042 cm. or [illegible] in.	0.031 cm. or [illegible] in.	0.025 cm. or [illegible] in.		
Weight:										
Grams....	4,[illegible]	26.41	[illegible]	[illegible]	6.37	6.31	[illegible]	107.65	4.42	[illegible]
Ounces ...	170.13	.93	.03	.03	[illegible]	[illegible]	[illegible]	3.79	[illegible]	4.79
Per cent.....	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.13	[illegible]	[illegible]	[illegible]	[illegible]

REMARKS.—The stone in this test was very much weathered; a fresh specimen from the same ledge would give a better result. It should make an excellent road metal.

Abrasion tests of road-building stones—Continued.

No. 31.—Locality of stone: Lynn, Essex County, Mass. 38, I (12—K). Name of stone: Felsite. Coefficient of wear, 14.66.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,802.57	56.77	2.48	1.20	12.85	8.12	22.71	89.08	4.22	136.44
Ounces	169.05	2.00	.09	.04	.45	.29	.80	3.14	.15	4.80
Per cent	96.05	1.14	.05	.02	.26	.14	.45	1.78	.08	2.73

REMARKS.—This stone is of a good quality, and very fair results should be expected from its use.

No. 32.—Locality of stone: Saugus, Essex County, Mass. 31, VII (24—W). Name of stone: Diabase. Coefficient of wear, 16.02.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,868.93	2.79	0.35	0.45	6.01	5.80	21.34	90.87	3.46	124.84
Ounces	171.39	.10	.01	.02	.21	.20	.75	3.19	.12	4.39
Per cent	97.38	.06	.01	.01	.12	.12	.43	1.82	.07	2.50

REMARKS.—The stone in this test was somewhat weathered; it should make a good road metal.

No. 33.—Locality of stone: Gloucester, Essex County, Mass. 43, II (28—U). Name of stone: Hornblende-granitite. Coefficient of wear, 11.03.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight										
Grams	4,806.21	8.05	0.06	1.56	29.92	7.75	21.00	121.08	4.37	181.37
Ounces	169.18	.28	.002	.05	1.05	.27	.74	4.26	.15	6.38
Per cent	96.12	.16	.001	.03	.60	.15	.42	2.42	.09	3.63

REMARKS.—This stone contains too much quartz to be a very good road metal.

No. 34.—Locality of stone: Lynn, Essex County, Mass. 38, I (12—N). Name of stone: Felsite. Coefficient of wear, 12.30.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,821.61	10.32	0.32	0.60	5.03	5.36	22.52	128.70	5.54	162.53
Ounces	169.72	.36	.01	.02	.18	.19	.79	4.53	.20	5.72
Per cent	96.43	.21	.01	.01	.10	.11	.45	2.57	.11	3.25

REMARKS.—This stone is rather brittle, but it should give fair results.

Abrasion tests of road-building stones—Continued.

No. 35.—Locality of stone: Saugus, Essex County, Mass. 31, VII (20—V). Name of stone: Diabase. Coefficient of wear, 18.25.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,878.09	6.97	0.17	0.61	3.08	3.43	13.01	89.29	5.35	109.59
Ounces	171.71	.25	.01	.02	.11	.12	.46	3.14	.19	3.86
Per cent	97.56	.14	.003	.01	.06	.06	.26	1.79	.11	2.19

REMARKS.—This stone should give excellent results.

No. 36.—Locality of stone, Lynn, Essex County, Mass. 38, I (10—C). Name of stone: Diabase. Coefficient of wear, 18.17.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,891.03	3.90	0.11	0.26	2.41	2.61	11.30	83.41	4.97	110.10
Ounces	172.16	.14	.004	.01	.08	.09	.40	2.94	.17	3.88
Per cent	97.82	.08	.002	.005	.05	.05	.22	1.67	.10	2.20

REMARKS.—This stone is rather coarse grained, but very hard and tough. It should give excellent results.

No. 37.—Locality of stone: Gloucester, Essex County, Mass. 43, II (32—F). Name of stone: Augite-nepheline-syenite. Coefficient of wear, 12.63.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,826.69	9.23	0.17	1.05	22.63	7.08	20.27	107.22	5.66	158.42
Ounces	169.90	.32	.01	.04	.80	.25	.71	3.78	.20	5.58
Per cent	96.53	.18	.003	.02	.45	.14	.41	2.14	.11	3.17

REMARKS.—This stone, though somewhat brittle, should make a fairly good road metal.

No. 38.—Locality of stone: Saugus, Essex County, Mass. 31, VII (12—W). Name of stone: Hornblende-granitite. Coefficient of wear, 8.99.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,724.44	48.48	0.44	0.96	14.40	6.30	25.42	174.97	4.59	222.49
Ounces	166.30	1.71	.02	.03	.51	.22	.89	6.16	.16	7.83
Per cent	94.49	.97	.01	.02	.29	.13	.51	3.50	.09	4.45

REMARKS.—This stone is very coarse and brittle, which renders it rather poor for use on roads.

Abrasion tests of road-building stones—Continued.

No. 39.—Locality of stone: Newbury, Essex County, Mass. 36, VI (32—G). Name of stone: Olivine-diabase. Coefficient of wear, 20.40.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,891.92	6.48	0.02	0.28	2.34	2.15	10.80	82.46	3.55	98.05
Ounces	172.20	.23	.001	.01	.08	.07	.38	2.90	.12	3.45
Per cent	97.84	.13	.0004	.01	.05	.04	.21	1.65	.07	1.96

REMARKS.—This stone is exceedingly hard and tough, and excellent results should be expected from it.

No. 40.—Locality of stone: Saugus, Essex County, Mass. 31, VII (16—V). Name of stone: Diabase. Coefficient of wear, 21.22.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,895.35	5.66	0.23	0.22	1.35	1.54	9.23	81.68	4.79	94.25
Ounces	172.32	.20	.01	.01	.05	.05	.32	2.88	.17	1.89
Per cent	97.91	.11	.01	.004	.03	.03	.18	1.63	.09	3.31

REMARKS.—This stone is exceedingly hard and tough, and excellent results should be looked for from it. It has the highest coefficient of wear obtained up to this date.

No. 41.—Locality of stone: Tisbury, Dukes County, Mass. Name of stone: Field stone (erratics). Coefficient of wear, 8.88.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,685.69	84.89	0.34	0.50	11.38	5.27	23.13	184.75	4.05	225.37
Ounces	164.94	2.99	.01	.02	.40	.19	.81	6.56	.14	7.93
Per cent	93.71	1.70	.01	.01	.23	.10	.46	3.69	.08	4.51

REMARKS.—Slightly weathered. Fair results should be expected.

No. 42.—Locality of stone: Plymouth, Plymouth County, Mass. Name of stone: Field stone (erratics). Coefficient of wear, 10.10.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,745.46	52.15	2.50	0.86	12.93	10.13	24.85	146.84	4.28	198.11
Ounces	167.04	1.84	.09	.03	.46	.36	.87	5.17	.15	6.97
Per cent	94.91	1.04	.05	.02	.26	.20	.50	2.94	.09	3.96

REMARKS.—The stone used in this test was, for field stone, very well preserved. Consists chiefly of granite. Fair results should be expected.

Abrasion tests of road-building stones—Continued.

No. 43.—Locality of stone: Salisbury, Essex County, Mass. 36, VI (7—P). Name of stone: Camptonite. Coefficient of wear, 16.76.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,873.74	1.75	0.10	0.45	4.57	4.10	14.20	95.95	5.14	119.37
Ounces	171.56	.06	.004	.02	.16	.14	.50	3.38	.18	4.20
Per cent	97.47	.03	.002	.01	.09	.08	.28	1.92	.10	2.39

REMARKS.—This stone has been used in road making for several years with good results.

No. 44.—Locality of stone: Rockport, Essex County, Mass. 43, IV (34—K). Name of stone: Hornblende-granitite. Coefficient of wear, 12.57.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,826.48	8.66	0.19	3.82	41.10	9.09	20.76	84.21	5.69	159.17
Ounces	169.89	.30	.01	.13	1.45	.32	.73	2.96	.19	5.60
Per cent	96.53	.17	.004	.08	.82	.18	.42	1.68	.11	3.18

REMARKS.—This rock is quite hard, but rather brittle. It should give fair results.

No. 45.—Locality of stone: Newbury, Essex County, Mass. 36, VI (29—I). Name of stone: Quartz-diorite. Coefficient of wear, 14.45.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,830.85	27.76	0.20	0.51	7.56	5.14	17.36	107.64	2.98	138.41
Ounces	170.05	.98	.01	.02	.27	.18	.61	3.79	.10	4.87
Per cent	96.62	.56	.004	.01	.15	.10	.34	2.15	.06	2.77

REMARKS.—This rock is very hard and rather tough. Good results should be had from its use.

No. 46.—Locality of stone: Providence, R. I. Name of stone: Grit (Carboniferous?). Coefficient of wear, 10.02.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,770.25	26.38	0.10	1.00	14.30	7.72	22.94	153.52	3.79	199.58
Ounces	167.91	.93	.004	.04	.50	.27	.81	5.40	.13	7.03
Per cent	95.40	.53	.002	.02	.29	.15	.46	3.07	.08	3.99

REMARKS.—This stone is quite hard, but rather brittle. Fair results should be expected.

Abrasion tests of road-building stones—Continued.

No. 47.—Locality of stone: Newburyport, Essex County, Mass. 36, VI (3—H). Name of stone: Diabase. Coefficient of wear, 16.10.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,867.41	4.00	0.13	0.48	5.36	5.77	19.60	92.85	4.40	124.19
Ounces	171.33	.14	.01	.02	.19	.20	.69	3.27	.15	4.37
Per cent	97.35	.08	.003	.01	.11	.12	.39	1.86	.09	2.48

REMARKS.—Although this stone is rather brittle, it ought to make a good road metal.

No. 48.—Locality of stone: Paxton, Worcester County, Mass. Name of stone: Granitoid gneiss. Coefficient of wear, 5.01.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,560.81	36.83	0.21	0.40	2.83	9.08	48.44	337.81	3.59	398.77
Ounces	160.54	1.30	.01	.01	.10	.32	1.71	11.89	.13	14.04
Per cent	91.22	.74	.004	.01	.06	.18	.97	6.76	.07	7.98

REMARKS.—This stone was very much weathered and had a decided tendency to crumble. It is very heterogeneous, and poor results should be expected from its use.

No. 49.—Locality of stone: "Iron Hill," Cumberland, R. I. Name of stone: Peridotite. Coefficient of wear, 9.42.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in.	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,784.23	0.93	0.35	1.35	9.71	8.30	26.20	166.33	2.60	212.24
Ounces	168.40	.03	.01	.05	.34	.29	.92	5.85	.09	7.47
Per cent	95.68	.02	.01	.03	.19	.17	.52	3.33	.05	4.24

REMARKS.—From the appearance of this rock a much higher test was looked for. It has a high cementing value and is very tough. Its low coefficient of wear is probably due to its softness.

No. 50.—Locality of stone: Gordon County, Ga. Name of stone: Chert. Coefficient of wear, 8.35.

	Size of mesh.								Loss.	Under $\frac{1}{16}$ in.
	6.31 cm. or $2\frac{1}{2}$ in.	3.18 cm. or $1\frac{1}{4}$ in	0.16 cm. or $\frac{1}{16}$ in.	0.13 cm. or $\frac{1}{20}$ in.	0.064 cm. or $\frac{1}{40}$ in.	0.042 cm. or $\frac{1}{60}$ in.	0.031 cm. or $\frac{1}{80}$ in.	0.025 cm. or $\frac{1}{100}$ in.		
Weight:										
Grams	4,720.10	36.64	0.52	1.51	21.86	8.85	29.57	177.21	3.74	239.52
Ounces	166.15	1.29	.02	.05	.77	.31	1.04	6.24	.13	8.43
Per cent	94.40	.73	.01	.03	.44	.18	.59	3.54	.07	4.79

REMARKS.—This rock was very much weathered. It is exceedingly hard and very brittle. It has been used as a road metal, and good results are said to have been obtained. At best it could only rank with granites and felsites.

Tabulated statement of coefficients of wear contained in the foregoing tables.

21.22. Saugus, Essex County, Mass. No. 40. Diabase.
20.79. Newton, Middlesex County, Mass. No. 19. Trachyte.
20.40. Newbury, Essex County, Mass. No. 39. Olivine-diabase.
20.37. Lynn, Essex County, Mass. No. 28. Diabase.
19.77. Lynn, Essex County, Mass. No. 27. Diabase.
18.25. Saugus, Essex County, Mass. No. 35. Diabase.
18.17. Lynn, Essex County, Mass. No. 36. Diabase.
16.76. Salisbury, Essex County, Mass. No. 43. Camptonite.
16.10. Newburyport, Essex County, Mass. No. 47. Diabase.
16.08. Saugus, Essex County, Mass. No. 29. Diabase.
16.02. Saugus, Essex County, Mass. No. 32. Diabase.
15.82. Medford, Middlesex County, Mass. No. 26. Diabase.
15.60. West Springfield, Hampden County, Mass. No. 16. Olivine-diabase.
15.55. Salem, Essex County, Mass. No. 6. Augite-diorite.
15.21. Quincy, Norfolk County, Mass. No. 24. Diabase.
14.71. Brookline, Norfolk County, Mass. No. 30. Olivine-diabase.
14.66. Lynn, Essex County, Mass. No. 31. Felsite.
14.45. Newbury, Essex County, Mass. No. 45. Quartz-diorite.
13.87. Everett, Middlesex County, Mass. No. 14. Olivine-diabase.
13.46. Duxbury, Plymouth County, Mass. No. 4. Hornblende-granitite.
13.21. Revere, Suffolk County, Mass. No. 15. Felsite.
12.63. Gloucester, Essex County, Mass. No. 37. Augite-nepheline-syenite.
12.57. Rockport, Essex County, Mass. No. 44. Hornblende-granitite.
12.50. Meriden, Conn. No. 17. Augite-diabase.
12.30. Lynn, Essex County, Mass. No. 34. Felsite.
12.16. Waltham, Middlesex County, Mass. No. 5. Hornblende-granitite.
11.65. Lee, Berkshire County, Mass. No. 9. Quartzite.
11.40. Brookline, Norfolk County, Mass. No. 21. Hornblende-diorite.
11.03. Gloucester, Essex County, Mass. No. 33. Hornblende-granitite.
10.69. Northampton, Hampshire County, Mass. No. 10. Hornblende-granitite.
10.16. Quincy, Norfolk County, Mass. No. 22. Hornblende-granitite.
10.10. Plymouth, Plymouth County, Mass. No. 42. Field stone (erratics).
10.02. Providence, R. I. No. 46. Grit (probably Carboniferous).
9.47. Nantucket, Nantucket County, Mass. No. 23. Field stone (erratics).
9.42. "Iron Hill," Cumberland, R. I. No. 49. Peridotite.
9.38. Pittsfield, Berkshire County, Mass. No. 3. Limestone.
9.28. Somerville, Middlesex County, Mass. No. 25. Diabase (very coarse grained).
9.09. North Attleboro, Bristol County, Mass. No. 11. Field stone (erratics).
8.99. Saugus, Essex County, Mass. No. 38. Hornblende-granitite.
8.88. Tisbury, Dukes County, Mass. No. 41. Field stone (erratics).
8.78. Mattapoisett, Plymouth County, Mass. No. 13. Field stone (erratics).
8.67. Newton, Middlesex County, Mass. No. 20. Conglomerate.
8.48. Somerville, Middlesex County, Mass. No. 8. Slate.
8.35. Gordon County, Ga. No. 50. Chert.
8.04. Lenox, Berkshire County, Mass. No. 2. Mica-schist.
6.58. Holden, Worcester County, Mass. No. 18. Field stone (erratics).
6.31. Tomkins Cove, N. Y. No. 7. Limestone.
5.93. Whitman, Plymouth County, Mass. No. 12. Field stone (erratics).
5.01. Paxton, Franklin County, Mass. No. 48. Granitoid gneiss.
2.85. Lee, Berkshire County, Mass. No. 1. Marble.

ECONOMIC GEOLOGY

OF THE

MERCUR MINING DISTRICT, UTAH,

BY

J. EDWARD SPURR.

WITH INTRODUCTION

BY

S. F. EMMONS.

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ECONOMIC GEOLOGY OF THE MERCUR MINING DISTRICT, UTAH.

By J. Edward Spurr.

INTRODUCTION.

By S. F. Emmons.

THE OQUIRRH MOUNTAINS.

TOPOGRAPHY.

From the base of the Wasatch Mountains on the east to that of the Sierra Nevada on the west stretches an arid region known to the early geographers as the Great American Desert, but more recently and accurately called the Great Basin, for the reason that it has no external drainage to the ocean. Geological investigation has shown that this region was once occupied by two large and distinct fresh-water seas, which have gradually disappeared by evaporation under the influence of slowly changing climatic conditions, until at the present day they are represented by relatively small saline lakes at the eastern and western extremities of the region, respectively.

The Great Basin has a physical structure peculiar to itself, consisting as it does of broad, nearly level valleys from 4,000 to 6,000 feet above sea-level, intersected by a series of narrow and often quite elevated mountain ridges, which trend with remarkable uniformity nearly due north and south. To these north-and-south ranges in the Great Basin, as well as to others in the similar region stretching southward beyond its limits through Arizona into Mexico, the name Basin ranges[1] has been given.

The Oquirrh Mountain range,[2] in which is situated the Mercur mining district, the subject of this report, is the first of these Basin ranges west of the Wasatch Mountains, from which its northern end is about

[1] G. K. Gilbert, U. S. Geological and Geographical Surveys West of the One Hundredth Meridian, Vol. III, Geology, Washington, 1874, p. 22.

[2] The general structure of the Basin ranges may best be seen by reference to the atlas of the Geological Exploration of the Fortieth Parallel. That of the Oquirrh Mountains is shown on Map III of that atlas, and also on the Tooele Valley sheet of the Geologic Atlas of the United States published by this Survey. In the latter, by an error in copying, Ophir and Lewiston canyons are incorrectly represented.

15 miles distant and separated by the nearly level Jordan Valley. While from out the many canyon gorges that score the western flanks of the Wasatch Range flow considerable mountain streams, sometimes reaching rivers in size, which furnish the water for the irrigation ditches that have made of the eastern half of the Jordan Valley an almost continuous series of gardens and grain fields, the western half of the valley, as it slopes up toward the base of the Oquirrh Mountains, still has the arid character of the desert, and the moment the river is crossed the ubiquitous sage brush (Artemisia) becomes the prevailing plant, as it is throughout the extent of the Great Basin.

The great difference in amount of precipitation in the two ranges is due not to the elevation alone, for the average elevation of the Wasatch Mountains is scarcely a thousand feet more than that of the Oquirrh Mountains, but to the greater width of the elevated portion. In the Wasatch this width is about 25 miles, while the base of the Oquirrh Mountains from foothill to foothill is only 5 to 10 miles wide, and the median ridge is extremely sharp and narrow. Hence, only here and there are running streams found in the canyons of the Oquirrh Range, and these streams are generally too feeble to furnish water for irrigation purposes or for moving machinery. Like other Basin ranges, the mountains are characterized by relatively short, steep slopes, which descend almost continuously from summit to base without forming distinct foothills, such as characterize most great ranges. This is especially marked at the northern end, where they descend almost perpendicularly to the shore of Salt Lake.

The Oquirrh Mountains proper are only about 30 miles in length, but to the north, in the same line of elevation, is the partly submerged mountain ridge forming Antelope Island, and to the south a low ridge beyond Fairfield Pass connects them with the Tintic Mountains. At Tooele Peak, about 20 miles south of Salt Lake, the range, which thus far is extremely narrow, widens considerably and sends forth spurs at right angles to its main trend, which form transverse, east-and-west ridges extending partly across the adjoining valleys. On the east these form the Traverse Mountains, which separate Cedar and Utah Lake valleys on the south from Jordan Valley on the north; on the west they are continued in the Stockton Hills, which separate in like manner Rush Valley from Tooele Valley, but there is no stream of sufficient volume to break through the dividing ridge and connect the drainage of the two divisions, as does the Jordan River on the east. The southern third of the range is not only wider but more elevated than the northern two-thirds, and reaches its culminating point in Lewiston Peak (10,623 feet elevation), near its extreme end.

At this peak head two important ravines or canyons: Ophir or East Canyon, which runs west into Rush Valley, and Pole Canyon, which extends southeast into Cedar Valley near the town of Cedar Fort. Between these two are the less important Lewiston Canyon,

south of and parallel to Ophir Canyon, at the head of which is situated the town and mining district of Mercur, and Fairfield Canyon, west of and parallel to Pole Canyon, in which are situated the Mercur mill and the branch railroad now building (1894–95) from Fairfield Junction on the Union Pacific Railroad (Tintic division) to the Mercur mine.

A line of depression, following the strike of a belt of soft, shaly beds, out of which Fairfield Canyon has been eroded, crosses the head of Lewiston and Ophir canyons, making very low passes between the three canyons. The Mercur mining district occupies the small basin thus formed at the head of Lewiston Canyon. The little town of the same name is situated in the bottom of the basin at the forks of the gulch, the narrow gorge below, which constitutes Lewiston Canyon proper, being cut through the harder limestones and sandstones that underlie the shale belt.

The general topographic structure of the region will be best understood by reference to the contour maps on Plates XXV and XXVI, the latter of which represents the Mercur Basin in detail; the former takes in the surrounding region, including Lewiston Peak and the southern end of the Oquirrh Mountains.[1]

ECONOMIC RESOURCES.

DISCOVERY AND DEVELOPMENT OF MINING DISTRICTS.

Although, according to Bancroft,[2] the existence of silver ores in the neighborhood of Great Salt Lake was known as early as 1857, the mining industry of Utah can not be said to have come into existence until 1869, when the advent of the transcontinental railroad and the consequent influx of Gentiles brought capital and enterprise to its aid.

The leaders of the Mormon Church had always opposed the development of mining by all the means in their power, fearing that the exciting and unsettling influence of that pursuit would turn away their

[1] As these maps were not prepared by members of the regular topographical corps of the Survey, it may be well to explain that the exigencies under which this work was undertaken rendered it necessary that the geologists should make their own topographical maps. The only instruments available were a small 14-inch plane-table, an alidade without telescope, an aneroid barometer, and an Abner level. Time also was very limited. The detailed map of the Mercur District was prepared by the writer, assisted by Mr. Spurr, the distance between two United States locating monuments, as given by the surveyors of Salt Lake City, being used as a base, and the elevation of the town above the Union Pacific Railroad at Fairfield Station being obtained from the engineers engaged in surveying the railroad line from that point to the Mercur mine. As the grading of this line was not completed until after field work was finished, it was not found practicable to represent it on the map.

The map on Pl. XXV was prepared later by using the Mercur map as a base and checking the distances from a triangulation made by Mr. Frank Anderson (of Palmer, Burton & Anderson, Engineers, Salt Lake City) to connect the Mercur, Glencoe, and Sunshine districts. The contours were sketched in on the plane-table by Mr. Spurr. It will not be surprising if maps made under such circumstances are not found to be absolutely accurate in every detail.

Our thanks are due to Mr. Anderson for copies of the underground maps of the Mercur and Marion mines, which he furnished to us with the kind permission of the owners of these properties, and which have been used by us in the preparation of various plates and sections; also to Mr. J. J. Hagerman for the hospitality extended in allowing us the use of his cottage as office and sleeping quarters, and to Messrs. James W. Neill, M. E., and A. E. Butts for valuable information with regard to the ore deposits of the region, with which they possessed much practical familiarity.

[2] History of Utah, by H. H. Bancroft, San Francisco, 1890, p. 741.

people from the more monotonous and peaceful occupations of agriculture, and thereby interfere with their great work of reclaiming the desert, and fearing, also, that the restless and sometimes rather lawless class of people who are attracted by mining excitements might prove a disturbing element in the population and tend to subvert their almost autocratic authority. This opposition, and the natural obstacles in the way of cheap mining or of an economic reduction of the generally rather refractory ores, acted as an effectual bar to the development or even the discovery of the mineral resources of the Territory in its early days.

It is to Gen. P. E. Connor, who commanded the California volunteers stationed at Fort Douglas, overlooking Salt Lake City, during the civil war, that credit is generally given for the first authentic discovery of silver ores in the Territory.

In 1863 General Connor found deposits of argentiferous galena at Little Cottonwood Canyon in the Wasatch Mountains, and on the west side of the Oquirrh Mountains, near the present town of Stockton. Others of his command discovered in the same year ores carrying lead and silver in Bingham Canyon, on the eastern slopes of the latter range, 20 miles southwest of Salt Lake City.

In December of the same year the West Mountain mining district was organized. It at first included the whole Oquirrh Range west of Jordan Valley; but later the western slopes were segregated under the name of the Rush Valley district, and the former name was retained for the eastern slopes, the working mines of which were confined practically to Bingham Canyon. Still later (1870) the western region was further divided into the Tooele, Rush Valley or Stockton, and Ophir or East Canyon districts.

In the Stockton district smelting furnaces were erected in 1864 by General Connor and his associates, and when at the close of the war the volunteer forces were disbanded, many of their members went into mining around Stockton, which gave to that town a fitful prosperity. With the failure of the smelting operations, which was a necessary result of the unfavorable economic conditions under which they were inaugurated, the district soon retrograded. In later developments the sanguine expectations of its discoverers have not been realized, though one mine has proved an important and heavy producer. Some exceptionally rich ores were found in Ophir Canyon, and the discoveries extended into the neighboring districts. Dry Canyon on the north and Lion Hill on the south formed part of the Ophir district; the indications of ore were traced still further south from the latter point, and in 1869 a small mining camp, called Lewiston, had already been started in the canyon of the same name, about 4 miles due south of Ophir. As the inhabitants drew their supplies of food largely from the neighboring settlement of Camp Floyd, the district was generally known as the Camp Floyd district.

Twenty miles further south, beyond a gap in the range known as Fairfield Pass, through which the railroad now runs, is another group of hills in the same line of elevation as the Oquirrh Mountains, but of less regularity of structure, known as the Tintic Mountains. Ore bodies were discovered on the western side of these hills in 1869, the first vein opened being the Sunbeam; the now famous Tintic mining district was organized in the same year, and has since become one of the most important producers in the Territory.

After the completion of the transcontinental railway, in the spring of 1869, the discovery of the great body of rich silver ore in the Emma mine at Little Cottonwood Canyon, from which over $2,000,000 was taken, and the building of large smelting plants along the railroad south of Salt Lake, which afforded a market for the refractory ores of the region, gave an immense impulse to prospecting and mining throughout the Territory. Within a comparatively few years mining districts sprung up and valuable mines were developed at widely distant points, and the Territory took rank as an important producer of the precious metals, especially of silver. Since 1880 it has ranked third among the States and Territories as a producer of silver, but its gold product has been of much less importance, and in the production of this metal it has held only the eleventh place. Hence a source of increase in the production of the latter metal, especially since the great decline in the price of silver, would prove most important to the mining community of the Territory, and it is partly for this reason that so much interest has been excited in the little mining district of Mercur.

Since 1869 railroad facilities have enormously increased, so that the cost of mining, and, what is even more important, of bringing the product of the mines to market, has been greatly diminished. A narrow-gauge railroad now runs from Salt Lake City around the northern point of the Oquirrh Mountains to Tooele and Stockton. A branch of the Rio Grande Western Railroad connects the mines of Bingham Canyon with the principal smelters at Sandy, south of Salt Lake City. Branches both of the Rio Grande Western and of the Union Pacific have been built to the Tintic mining district, the former entering it from the east, the latter from the west. A short branch of the latter road, completed since the present work was undertaken, connects the mine of Mercur with its mill in Fairfield Canyon and with the Union Pacific line at Fairfield station. The grades on all these roads are low for a mountainous country, and coal is produced abundantly in the Territory by mines situated along the eastern flanks of the Wasatch uplift, both to the northeast and the southeast of Salt Lake City. The conditions would therefore seem to be favorable for the development of an important and permanent mining industry, for experience has shown that the mountains abound in rich mineral deposits, and that a great many instances of unsuccessful mining are to be attributed to ignorance or incompetence of the management rather than to failure in the quality or quantity of the ore.

PRODUCTION OF MINING DISTRICTS.

The relative economic importance of mining districts is necessarily gauged by the values of their products, though there may be other qualifying circumstances in special cases that produce valid exceptions to the rule. Hence the following table of the production of the several most important mining districts of the Oquirrh Mountains has been prepared for purposes of comparison. The material has been largely compiled from the reports of the Commissioner of Mining Statistics (1870–1876) and from those of the Director of the Mint (1881–1893), and though necessarily incomplete, the figures represent approximations that sustain a uniform proportion one with another, and hence are valid for comparative purposes.

Production of Oquirrh mining districts to Jan. 1, 1894.

District.	Gold.	Per cent.	Silver.	Per cent.	Aggregate coinage value.	Per cent.	Lead.
	Ounces.		*Ounces.*				*Tons.*
Tintic	127,000	47.8	18,866,000	54.00	$27,017,080	54.00	66,000
Bingham	113,000	42.5	12,690,000	36.35	18,742,818	37.00	250,000
Ophir	5,600	2.2	2,780,000	8.00	3,490,231	6.90	49,000
Stockton	1,000	0.4	520,000	1.52	692,980	1.30	1,000
Camp Floyd	19,000	7.1	46,000	0.13	452,238	0.80	.....
Total	265,600	.....	34,902,000	.....	50,395,347	.....	366,000

The first shipment of ore from the Territory was from Bingham. According to Bancroft[1] this shipment consisted of a car load of copper ore that in June, 1868, was hauled by wagon to the Union Pacific Railroad at Uinta and forwarded by Walker Bros. to Baltimore, Md.

Bingham Canyon is also the only district in Utah where placer mining has been carried on with profit to any considerable extent. It is estimated that in the first five years, commencing with 1868, 5,000 ounces of gold per year were obtained from it. After that placer mining was neglected, owing to the growing importance of silver-lead ores. From scattering and not always accurate sources of information its total production of placer gold has been estimated in round numbers as 40,000 ounces. The other gold given in the table above is from deep mines, the values from some of which are largely in this metal.

Recent deposits of oxidized copper ore are also found in the detrital material of the canyon, and it was from them that the shipment mentioned above was probably made. The deposits are evidently formed by the leaching of copper ores below the surface, yet no copper minerals are said to be found in the ore bodies until considerable depth is reached. The succession of minerals in depth is said to be, first, a zone carrying zincblende and galena in about equal proportions; then a zone with galena and zincblende in the proportion of about 4 to 1; then a zone of iron pyrite, and below this a mixture of copper pyrite.[2]

[1] History of Utah, by H. H. Bancroft, San Francisco, 1890, page 741.

[2] Personal communication from A. F. Holden.

Bingham has been a large producer of lead ores, and the estimate gives an aggregate of about a quarter of a million tons of this metal as its total yield.

Its silver production increased steadily from about 65,000 ounces in 1871 to nearly 1,000,000 ounces in 1879, which is the maximum annual production. It has since varied with the economic conditions. The present annual production is about 600,000 ounces of silver and 7,000 ounces of gold.

The production of Ophir began to assume importance in 1870. The ores were very rich; some from the Mono mine are said to have contained 50 per cent of silver, and small shipments from the Silveropolis to have averaged over $6,000 per ton in 10-ton lots. In its palmy days its annual product probably amounted to over half a million ounces of silver, but its rich bodies were soon exhausted, and the camp suffered a relapse much earlier than did Bingham. For 1893 its product is estimated at about 150,000 ounces of silver and 400 ounces of gold. Its ores carry a much smaller proportion of lead than those of Bingham, and the total production of this metal in the district is estimated at less than 50,000 tons.

The production of the Stockton district has extended over a longer period than that of either the Ophir or Bingham, but has been very irregular, and, as shown by the table, is very much less in aggregate amount.

Still less important has been the Camp Floyd (or Lewiston) district. During the ten years from 1871 to 1881 it has probably produced about 46,000 ounces of silver, which is the total mineral production of the camp for that time, since the ores then worked contained no lead, copper, or gold. The gold production of its successor, the Mercur district, which became important in 1892, amounted in that and the succeeding year to about 19,000 ounces, and as the gold ore is quite free from silver and lead, this is also the total production of the camp for that time.

Tintic district, in 1871, produced about 26,000 ounces of silver, and developed but slowly during the time when Bingham and Ophir were enjoying their greatest prosperity. The advance in its production was, however, very steady and persistent up to the time of the great drop in the price of silver. Its maximum product was probably the yield of 1890, which is estimated at 3,800,000 ounces of silver and 24,000 ounces of gold. The product for 1893 was about 1,900,000 ounces of silver and 15,000 ounces of gold. Copper is an important constituent of some of the ores, but it is especially difficult to arrive at accurate estimates of the amount produced, as it is generally shipped to distant smelters. It is roughly estimated that 15,000 tons of this metal have been produced in the district.

If Tintic be considered as one of the Oquirrh Mountain districts—and geologically it undoubtedly should be—the mineral wealth of this range has proved itself of equal if not of greater importance than that

of its far greater neighbor, the Wasatch Range, and together, at the present day, these furnish over two-thirds of the precious-metal product of the Territory.

If the metals are considered separately, it is to be noted that the total silver production of Utah for 1893 was about 6,358,000 ounces, of which the Oquirrh districts produced 2,707,000 ounces. The total gold production, on the other hand, for the same period, was about 42,000 ounces, of which the Oquirrh districts produced 38,000 ounces.

In estimating the commercial value of this product, with gold at $20 per ounce and silver at $0.73 per ounce, the total value of the Oquirrh ores for 1893 was $2,736,100, while that of the ores from the rest of Utah was $2,745,230; so that, considered in this way, the Oquirrh districts have furnished half the precious-metal product of the Territory.

CAMP FLOYD OR MERCUR MINING DISTRICT.

Although the town of Lewiston was already established as a mining camp in 1869, but little prospecting seems to have been done until 1870 or later.

The following is the first notice of the district that appears in print:[1]

Camp Floyd district.—This district adjoins Ophir or East Canyon district on the south. It is comparatively new and the claims are not yet much developed. The outcroppings of veins are well defined and are not so high up on the mountain as at Lion Hill. The winters are not so severe, and it is claimed that miners can work in open claims during the season. Among the principal claims are the Sparrowhawk, Silver Cloud (reported to have been recently sold to an English company), Mormon Chief, and the Grecian Bend. There is also a vein affording cinnabar of low percentage.

Sparrowhawk.—This claim, opened during the summer by Mr. McMasters, shows a considerable body of shaly quartz of a dull, bluish-gray color, and coated with films of chloride of silver. The vein is marked by very heavy quartz croppings. The thickness at the open cut, from which most of the silver-bearing ore has been taken, is about 50 feet, but it is irregular. A large portion of these croppings is apparently quite free from ore in paying quantity. In August last year there was a large pile of ore on the dump, estimated at 100 tons of first-class and the same quantity of second-class ore.

Grecian Bend.—This claim is a short distance beyond the Sparrowhawk and may be a prolongation of the same vein. This and the Mormon Chief claim beyond it are adjoining claims, each having 2,000 feet upon the lode. They are characterized by an enormous outcrop of quartz, stretching up the side of the mountain for a mile or more. It rises from 20 to 50 feet or more in height, and has an irregularly broken, precipitous face. It pitches into the hill at an angle of about 20°, and the general direction of the cropping is 10° south of west. This outcrop is in general quite hard and compact, and gives little indication of being ore bearing, though the color is dark, and it much resembles the quartz at the Sparrowhawk claim, where chloride of silver has been found. Very little work has been done on either of these claims. With the exception of two small pits upon the lower edge of the cropping, the mass of the vein is untouched and awaits vigorous work, conducted upon a liberal scale, to break into the rocky mass and show whether it is ore bearing or not. At one of the excavations there are some small streaks of ore, which, it is said, assay well for

[1] Mineral Resources west of Rocky Mountains for the year 1871, R. W. Raymond, Washington, 1873, p. 313.

silver. At that place the ledge appears to be split up into several layers, but all of them are conformable to the strata of shaly limestone above and below. The indications are sufficient to justify the expenditure of some money in prospecting the ground, especially along the contact of quartz with the wall rocks.

In the same reports, for the year 1872 (p. 255), it is said that an English company which had acquired the Sparrowhawk, Last Chance, and Marion mines had worked them actively, employing 40 to 50 miners, and that the company had also built a 20-stamp mill, capable of reducing 30 tons of ore per day. The developments of free-milling ore in the Mormon Chief, Grecian Bend, Silver Cloud, Star of the West, Stafford, Carrie Steele, and other mines are also spoken of in the most encouraging terms, and a second stamp mill is said to have been recently completed at Fairfield.

The United States report on Mineral Resources for the year 1873 (p. 276) notes that the mill of the English company had ceased running on its own ores, because "they are very difficult to assort, and of too low grade to pay for extraction without sorting." In the description of the mineral composition of the ores no mention is made of the antimony with which they are impregnated, nor of the possibility that it may have been the presence of this metal that interfered with the amalgamation. The mill worked during the year mainly on custom ores, and it is said to have produced, up to the end of November, 56 bars of bullion, worth over $52,000, while the tailings on hand were worth $40,000. The camp probably reached its maximum production of silver during this year (1873), for which 11,000 ounces are reported. In 1874 the mining operations are reported to have been unimportant; the mill was running on custom ores.

For the next seven or eight years a small but somewhat continuous production of silver is reported, probably obtained from small bodies of chloride ore near the surface. The average annual output of the camp during the period of its former activity may be estimated at about 4,000 ounces.

Early in the eighties the camp became almost entirely deserted, and of the town of Lewiston only a house or two remained. So completely was it forgotten that the name was given by the postal authorities to another town in Cache County, Utah, and when mining revived, some ten years later, a new name had to be given to it.

The mines mentioned in the above reports are the silver mines, which are now completely abandoned. The projecting outcrop of dark, siliceous rock in which the silver ores were found still goes by the name of the Silver ledge. The occurrence of gold, which constitutes the present value of the camp, was not mentioned in the above-quoted reports, although it is evident that the gold-bearing ores were noticed by the early explorers.

The report on Mineral Resources for 1873 has the following:

In Camp Floyd several deposits of cinnabar have been discovered. On the Jenny Lind an incline 50 feet deep has been sunk. Experiments made with several hun-

dred pounds of ore gave the average percentage of quicksilver in the assorted stuff as 4 per cent. The New Idria is located on the same vein as the one just mentioned. In a 20-foot incline sunk on it 4 feet of ore are reported to be exposed. It has the same value as that from the Jenny Lind.

From this and the mention in the quotation from the report for 1871 of a "vein affording cinnabar of low percentage," it is evident that what is now known as the Gold ledge, which is but a hundred feet or so above the Silver ledge, had been remarked, but its gold contents had evidently not been suspected. This is hardly surprising, considering the usually low percentage of this metal, and the fact that it is never visible in the ores, even with the aid of a glass.

About 1890 interest in the camp was revived through the discovery that at an horizon about 100 feet above the Silver ledge, or stratum from which the antimonial silver ores of the early days had been extracted, a line of decomposed ocherous-looking rock, often stained red by cinnabar or realgar, carried a small but very persistent percentage of gold. The old and generally abandoned claims were bought up and consolidated into several groups. The most important company of the present day had a number of claims on the south side of the ravine immediately above the site of the old town. One of these claims was called the Mercur, probably on account of the occurrence of cinnabar, or mercuric sulphide, on the outcrop of the Gold ledge witihin its limits. From this the company and the little town that soon grew up derived their names.

The managers of the Mercur Company for some time found considerable difficulty in devising a process which would reduce their ore at a profit. It was of too low grade and too free from fusible metals, like ead, to be profitably smelted. Repeated attempts at amalgamation were unsuccessful, and it is said that in the mill at first erected to treat the ores they yielded less than the amount of the running expenses. Successful experiments were finally made with the MacArthur-Forrest cyanide process, which dissolves the gold in a solution of cyanide of potassium, from which it is precipitated by peculiarly prepared shavings of metallic zinc.

On account of the scarcity of water the leaching mill was not erected in Lewiston Canyon, near the mine, but in Fairfield Canyon, 3 or 4 miles distant, and half way to Fairfield Station. Here a spring furnishes a fine flow of water from a bed of shale at the base of the alternating siliceous and calcareous strata which are folded into a syncline in the bed of Pole Canyon.

In this mill the treatment of the ore, which is little else than a decomposed limestone or porphyry, has proved most successful. In practice it is very coarsely crushed for leaching, so that the tailings are large pieces of rock about half an inch in diameter. Hence, in spite of the expense of hauling the ores on poor roads over the divide separating the two canyons, they have paid very generously to their owners.

In 1892 the Mercur mine produced upward of 4,000 ounces of gold,[1] and up to November, 1894, the company had paid $175,000 in dividends.

In 1893 the Marion mine, formed by the consolidation of the Sparrowhawk, Marion, and other claims which in former days had been extensively worked for silver, became productive. Its workings are situated on the north side of the gulch directly opposite the claims of the Mercur mine, and the spurs on which these two working mines are located are known from them as Mercur and Marion hills respectively. At the east foot of Marion Hill, and just north of the town, a mill was built for treating the ores of the Marion mine by the cyanide process. This mill has been running successfully ever since, and, it is claimed, can profitably treat an ore carrying only $4 in gold per ton. Water for the mill is obtained from the Sparrowhawk spring, with which it is connected by about 2 miles of pipe. The Sparrowhawk spring is situated on the same belt of water-bearing shale as the Mercur spring, but several miles to the northwest, near the summit of the divide over which the road from Mercur to Ophir passes.

The production of the district for 1893, which is the combined product of the Mercur and Marion mines, was between 14,000 and 15,000 ounces of gold.

In the summer of 1894 the Geyser Company, whose claims are situated on the northeast side of Marion Hill, commenced work upon another cyanide mill, situated a few hundred yards above the Marion mill. This was finished too late in the season to permit of much production. The scarcity of water is a decided obstacle to milling in the canyon, for there is no running water, and the known springs have a limited supply of water and are all taken up. There are two water-bearing belts that cross the canyon, which are indicated on the accompanying geological map (Pl. XXVI). On the upper of these belts are the Mercur, Sparrowhawk, and Franklin springs; on the lower the Silver Cloud and Surprise springs are the only ones that have yet been developed.

At the time of examination (October–November, 1894) the grading of a branch railroad destined to connect the Mercur mine and mill with the Union Pacific Railroad at Fairfield junction was nearly completed. It is to be expected that with the completion of this railroad some of the other claims may be more vigorously explored for deposits of gold-bearing ore and be eventually added to the list of producing mines.

[1] Production of gold and silver in the United States for 1893, by the Director of the Mint, Washington, 1894, p. 113.

GENERAL GEOLOGY.

STRUCTURE.

The only geological investigations made of this range have been in the nature of reconnaissances, and were conducted by the earlier exploration parties about twenty-five years ago. As geologist of the Wheeler survey, Mr. G. K. Gilbert,[1] in the years 1871 and 1872, and Mr. E. E. Howell,[2] in the years 1872 and 1873, visited portions of the Oquirrh Range, and in the summer of 1869 the writer, as one of the geologists of the Fortieth Parallel Survey, traversed the range from north to south. The following extract from his report[3] gives the general features of its structure, as then determined:

> They [the Oquirrh Mountains] are composed mainly of Carboniferous limestones and quartzites, which the forces of contraction, acting almost equally in either direction, have compressed into a series of complicated folds, in which the prevalent strike, however, is in a northwesterly direction. The folding of these beds has been accompanied by a very considerable metamorphism and by the injection of porphyritic dikes, together with subsequent mineralization in the more disturbed districts.
>
> The southwestern portion of the range, to the west of the main ridge, is a quaquaversal uplift in the Wasatch limestone, in the center of which, at Ophir City, a faulting at right angles to the longer axis of the uplift has brought up the upper beds of the Cambrian. From Ophir City as a center these limestone strata all dip away—steeply toward the west, more gently toward the north, east, and south.
>
> The main crest of the range between Tooele and Lewiston peaks is the remnant of the flat arch of an anticlinal fold, which descends both to the north and to the south, resulting at the south point of the range in two minor synclinal folds, in Pole Canyon and in the canyon south of Lewiston, and a similar synclinal fold to the north in the region between Soldier Canyon and Tooele Canyon. In the region between Tooele Peak and Connor Peak, more particularly in Bingham Canyon, which is almost entirely in the beds of the Weber quartzite, the structure lines are much more difficult to follow, and evidently the general system of folding observed in the southern portion is much complicated by minor folds; but its structure is in general that of a synclinal fold in these beds, while at the northern point of the range, beyond Connor Peak, the beds of the Lower Coal Measure group are found to be pushed up and crumpled together in short, sharp folds, giving, in an east and west section across the northern point, no less than three small anticlinals, while the tendency of all the beds is to dip steeply beneath the waters of the lake.

With regard to this northern portion of the range, there is still much obscurity, the time available for the earlier examinations having been too limited to admit of the satisfactory working out of its complicated structure. Mr. Gilbert[4] suggested in his report that the abrupt termination of the northern end of the range and the steep dips of its strata are due to faulting. Good ground for such an assumption may be

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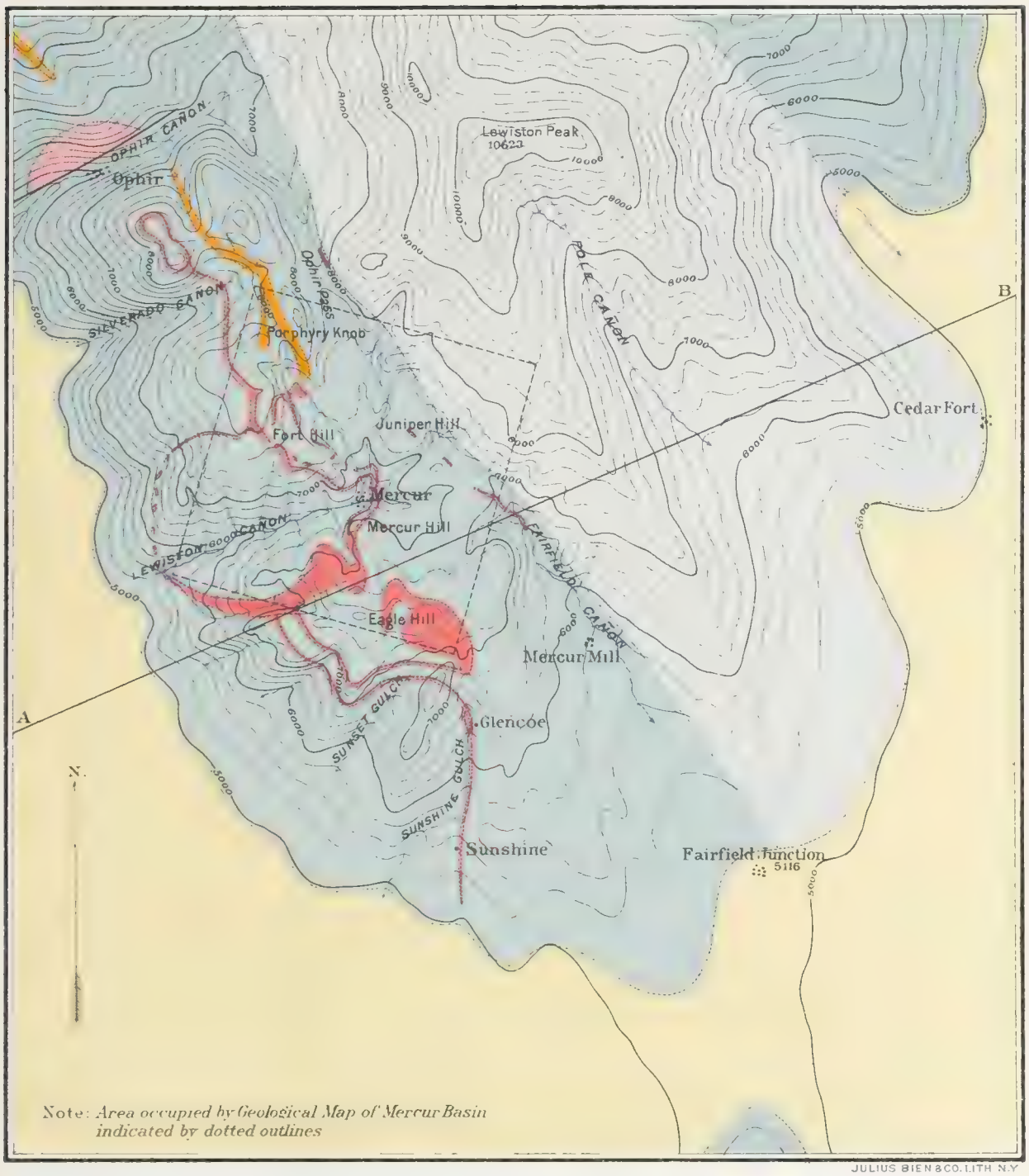
[1] U. S. Geological and Geographical Surveys West of the One Hundredth Meridian, Vol. III, Geology, Washington, 1875, p. 25.

[2] Ibid., p. 237.

[3] U. S. Geological Exploration of the Fortieth Parallel, Vol. II, Descriptive Geology, Washington, 1877, p. 443. See also Vol. I, Systematic Geology, p. 736, and analytical geological map x.

[4] Op. cit., p. 26.



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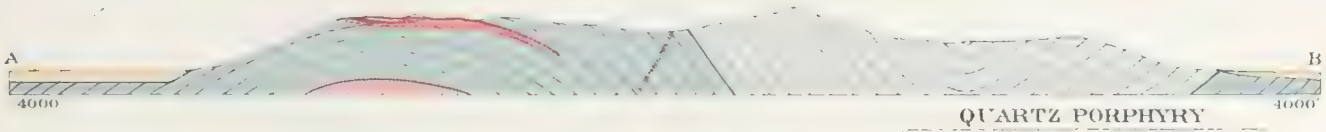


PLEISTOCENE	UPPER CARBONIFEROUS	LOWER CARBONIFEROUS	CAMBRIAN	QUARTZ PORPHYRY: BIRD'SEYE PORPHYRY	QUARTZ PORPHYRY: EAGLE HILL PORPHYRY

PRELIMINARY GEOLOGICAL MAP OF THE SOUTHERN END OF THE OQUIRRH MOUNTAINS

BY

S. F. EMMONS and J. E. SPURR.

Scale

0 8000 16000 24000 FEET

Contour Interval 250 Feet

found in the topographic form of the northern spurs, a portion of which is well shown in the frontispiece of his admirable memoir[1] on the Pleistocene phenomena of the eastern half of the Great Basin, or the Lake Bonneville region.

With regard to the southern portion of the range, the description above quoted is essentially correct. South of Tooele Peak the range consists of two great anticlines with an included synclinal fold, the trough of the latter occupying the depression of Pole Canyon. The axes of these folds have a direction N. 25° to 30° W., or about 30° more to the westward than the crest of the range, and all three appear to pitch downward both northwestward and southeastward from about the line of Ophir Canyon. Hence, the western anticline, which forms the projecting southwestern portion of the range and which was the subject of study in the present investigation, is an elongated quaquaversal, with the center of the arch, where the lowest beds are exposed, at Ophir Canyon. The axis of this fold runs very near the western foothills of the range, so that while at these foothills the dip of the beds is strongly toward the valley from Stockton round to Fairfield Pass, by following up any of the western canyons one comes, within a mile or two from its mouth, to beds dipping easterly, or into the range and away from the valley. In all these folds the dip of the beds grows steeper as the distance from the axis of the fold increases, and in a broad way the eastern sides of the anticlines are the steeper, the angles of dip reaching 60° to 70°.

Faulting in this portion of the range has been an extremely subordinate phenomenon as compared with plication, the fault in Ophir Canyon being the only one observed in which there was a large displacement of the adjoining beds.

SEDIMENTARY ROCKS.

The exact geological horizon of the beds forming any of the Basin ranges is always difficult and often impossible to determine, since they are completely isolated by the more recent valley deposits, which occupy about two-thirds of the aggregate surface and so effectually conceal both form and character of the rock surface beneath that it is impossible to establish a stratigraphical connection or valid correlation with the beds of the nearest ranges. The parts of these ranges now exposed to observation are in reality only the upper and steeper portions of mountain masses of more than double their basal width.

Although fossils are comparatively abundant in the rocks of the Oquirrh Range, with the exception of a few Cambrian forms obtained from the quartzite and shales of Ophir Canyon, most of those collected thus far have been of types that range from the bottom to the top of the Carboniferous. Hence, in establishing probable horizons to correspond with those of the type section in the Wasatch Mountains, it has

[1] Lake Bonneville, Mon. U. S. Geol. Survey, Vol. I, Washington, 1890.

been necessary to base the determinations largely on general sequence of conditions of sedimentation.

The thickness of the members of the Paleozoic column, as recognized in the Wasatch Mountains by the geologists of the Fortieth Parallel Survey, was, in round numbers, as follows:

Paleozoic section in the Wasatch Mountains.

System.	Formation.	Average thickness.
		Feet.
Carboniferous (15,000 feet)	Upper Carboniferous limestone (including Permian.)	2,500 to 3,000
	Weber quartzites, with a few thin beds of limestone.	5,000 to 7,000
	Wasatch limestone (with Waverly and Devonian fossils at the base).	7,000
Devonian (2,000 feet)	Ogden quartzite	1,000 to 1,250
Silurian (1,000 feet)	Ute limestone	1,000 to 1,250
Cambrian (12,000 feet)	Big Cottonwood quartzite series (clay-slates at top).	12,000
	Total, about	30,000

Of these formations, only the Cambrian quartzite, Wasatch limestone, and Weber quartzite have been definitely recognized in the Oquirrh Mountains, no fossils of Permo-Carboniferous, Devonian, or Silurian types having yet been discovered. Still, it can not be safely assumed that these formations are not represented until a more exhaustive search for their fossils has been made.

In the Cottonwood region of the Wasatch Range, and northward from there, the lithological separation of Weber quartzite from Wasatch limestone is sharp and distinct, the one being almost as free from limestone as the other is from siliceous beds. To the southward, however, in the Timpanogos Peak region, the upper part of this great limestone zone consists of a series of alternating beds of quartzite and limestone, which were called the Intercalated series, and which probably in part represent the Weber quartzite.

In the Oquirrh Mountains the Weber quartzite was supposed, in the earlier explorations, to be typically developed in Bingham Canyon, where the formation is predominantly quartzitic. There, according to Mr. A. F. Holden, who has had opportunities of studying the series in detail, it consists, in round numbers, of 500 feet of shales and 350 feet of limestone, in beds 50 to 100 feet thick, interbedded with quartzites, forming an aggregate thickness of 6,700 feet of rock strata. These beds belong to the eastern member of the eastern anticline, and corresponding beds will probably be found in the upper part of the trough of the Pole Canyon syncline.

On the west side of the range, Mr. Spurr has carefully measured the section of the western anticline exposed by the erosion of Lewiston Canyon, and finds about 12,000 feet of beds from the lowest point under the crest of the anticline up to the top of the ridge dividing the head of Lewiston Canyon from Pole Canyon. Of these the lower half is mostly of limestone, and the beds carry Lower Carboniferous fossils,

while the upper half, which consists of alternating beds of limestone and of calcareous sandstone that has the outward appearance of quartzite, carries Coal Measure or Upper Carboniferous forms.

Inasmuch as the Coal Measure forms in this region extend both above and below the horizon of the Weber quartzite, and have a vertical range of 10,000 to 15,000 feet, it is necessary to depend largely upon lithological characteristics and stratigraphical data for the determination of horizons. When, as in this case, the detailed examination has not been extended completely across the range, correlation of beds as widely separated as are these from the beds of Bingham Canyon must be somewhat hypothetical. It seems probable that these upper beds, the Intercalated series of Lewiston Canyon as they have been called, correspond to the upper part of the Wasatch limestone as developed in the Cottonwood region, and belong below the Bingham Canyon beds.

The Lower Carboniferous limestones of Lewiston Canyon constitute the ore-bearing horizon of the Mercur district. Above them, and yet beneath the more siliceous beds of the Intercalated series, are beds of clay-shales, thus showing a sequence of general conditions of sedimentation (from calcareous, through argillaceous, to siliceous beds) similar to those which so generally prevailed at these horizons throughout the Rocky Mountain region of Colorado. A second series of siliceous beds, about 600 feet in thickness, occur near the base of the Lewiston Canyon section, and it was at first thought that these might correspond to the Ogden quartzite of the Wasatch section; but Lower Carboniferous forms were found both in and below them. Hence the base of the Wasatch limestone is not exposed in this canyon.

On the north side of Ophir Canyon, and a few hundred yards north of its bed, a peculiar arch of Cambrian quartzite has been uplifted by the throw of a fault running parallel to the course of the canyon and at right angles to the axis of the anticline. Above the quartzites on the north side of the canyon are characteristic greenish clay-slates, carrying primordial trilobites, and back of these again rise 2,000 feet of limestone cliffs, in which sub-Carboniferous or Waverly fossils have been found near the top of the wall. On the south side of the canyon a still steeper wall of limestone, 2,000 feet in height, forms the northern face of Lion Hill. Near the summit of this hill is an ore-bearing zone that probably occupies very nearly the same horizon as that which is known in Lewiston Canyon as the Silver ledge. If this assumption be correct, the base of the south wall of Ophir Canyon is at least 1,000 feet lower in horizon than the lowest beds exposed in Lewiston Canyon.

What the throw of the Ophir Canyon fault is can not be definitely settled until the faunal correspondence of given horizons on either side of the canyon shall have been more accurately determined. From present knowledge it is probable that it may amount to 1,000 or 2,000 feet. Ore deposits have been opened on the north side of the fault in the Lower Carboniferous beds of Dry Canyon, and from there down-

ward to the shale beds, just above the fault, which separate the limestones from the underlying Cambrian quartzite; while on the south side they are mainly confined to the beds near the top of Lion Hill. Hence it is apparent that there must have been other causes beyond and independent of the geological horizon of the beds that have influenced the deposition of ore within them.

IGNEOUS ROCKS.

In the Fortieth Parallel report already quoted a connection was suggested between the occurrence of igneous rocks and ore deposition, and later investigations in various parts of the Cordilleran region have not only shown such a connection to be very general and widespread but have indicated that in many cases the connection is more than a coincidence and probably has a genetic basis.

In the Oquirrh Mountains there are no large exposures of eruptive rocks such as result from surface outflows, except possibly on the extreme eastern spurs near the Traverse Mountains. The bodies that had hitherto been observed, as well as could be determined from the generally altered and rather obscured condition of their outcrops, were dikes and irregular intrusive bodies or stocks. In Bingham Canyon it is said to be a matter of common observation that the ore is found only in the vicinity of one of the bodies of porphyry that occur there.

The present investigation has shown that the porphyries found in the Mercur district occur not only as dikes and stocks, but largely as thin sheets, generally parallel to the stratification; and it is immediately beneath certain of these sheets that the principal ore deposition has taken place.

There are two varieties of porphyry in this district, one of which, the Eagle Hill variety, is very like the White porphyry of the Leadville district in internal structure; the other, here called the Bird's-eye porphyry, is more like the Gray porphyry of Leadville. Both varieties occur as intrusive sheets spreading out between the strata, with which they preserve a general parallelism, though at times they cross at a low angle from one bedding plane to another. The vents or channels through which the magma that formed these sheets was forced up from below are not sufficiently exposed by erosion to admit of their being exactly located, but such evidence as is available shows that they are probably in a general zone running parallel with the strike and on the east side of the axis of the anticline. Actual dikes crossing the strata at right angles were observed only in the case of the Bird's-eye porphyry at the head of Silverado Canyon. This variety has been traced from the northern edge of Mercur Basin nearly to Ophir, and is probably the same rock that forms the dike-like wall projecting from the limestone cliffs on the north side of Ophir Canyon. The Eagle Hill porphyry finds its greatest development on the southern edge of the Mercur Basin, around Eagle Hill, and it is probable that the channel

through which it was forced up is somewhere in this vicinity. From here it has been traced southward nearly to the end of the range, and northward across the Mercur Basin to Lion Hill, thus overlapping the Bird's-eye porphyry at a slightly lower horizon.

As regards the age of these rocks, it can only be said with certainty that they are older than the Pleistocene and younger than Carboniferous rocks, for there are no rocks of intermediate age in this region that will serve to fix the time of eruption more closely. It is probable that they were intruded into the sedimentary strata before the latter were plicated, for it is difficult to conceive that the molten rock could have followed the bedding planes so closely as it did after they had been folded into anticlines and synclines, and necessarily more or less broken and displaced. Moreover, the porphyry is faulted with the strata in the minor fracturing that has taken place in the vicinity of the ore deposits.

The determination of the date of the orographic movements that have affected this range is, strictly speaking, subject to the same limitations that obtain for that of the porphyritic eruptions. It is possible, however, to arrive at an estimate of the date which is at least approximately correct by a consideration of the structure of the Great Basin ranges as a whole. Mr. Clarence King,[1] as a result of the Fortieth Parallel investigations, concludes: First, that the Great Basin region suffered a continental or epeirogenic elevation at the close of the Carboniferous, in consequence of which no Mesozoic sediments were deposited in it from the Wasatch Range (longitude 112° W.) westward to Battle Mountain (longitude 117° W.); second, that the Basin ranges were plicated during the post-Jurassic or pre-Cretaceous movement; third, that during post-Cretaceous or Tertiary time they were affected by dynamic movements which produced fracturing and faulting rather than plication.

The probability, therefore, is that the porphyritic intrusions took place in post-Jurassic times, and that these rocks are of relatively ancient date as compared with most of the igneous rocks of the Great Basin region, which were poured out upon the surface during the Tertiary. Of these later effusive rocks none have yet been observed in the Oquirrh Mountains proper, though it is probable that those of the Traverse Mountains, on their eastern flanks, may be found to belong in this category.

ECONOMIC GEOLOGY.

MERCUR DISTRICT.

The only recent publication upon the economic geology of the Camp Floyd or Mercur district, so far as known, is a paper read before the Colorado Scientific Society, at Denver, in the summer of 1894, by Mr. R. C. Hills, who kindly furnished to the present writer an advance copy at the commencement of this investigation.

[1] U. S. Geol. Expl. Fortieth Parallel, Vol. I, pp. 734 et seq. and 744.

This paper, which was based upon a prolonged and most thorough examination of the workings of the Mercur mine, was of great assistance in the present work, and although the conclusions here arrived at differ in some respects from those of Mr. Hills, this investigation has confirmed his observations in the most essential points.[1]

At the time the present investigation was undertaken the opinion generally entertained with regard to the geological relations of the ore deposits in the Mercur district by those who had given most time and labor to the question was briefly as follows:

Two ore-bearing beds, about 100 feet apart, exist near the middle of a great series of limestone strata. The lower of these two beds consists of quartzite or dark, silicified limestone, brecciated and porous, carrying silver with some antimony and copper, but no gold, and is called the Silver ledge. The upper, known as the Gold ledge, is a zone or bed of decomposed, sometimes bleached, sometimes red or yellow, limestone and shale, which carries over considerable areas realgar and cinnabar, together with a low but comparatively uniform percentage of gold, but no silver.

Although it had been remarked that the distance between these two zones or beds varies somewhat from one point to another, it was nevertheless believed that each followed a definite horizon or bed in the limestone series, and the Silver ledge, whose outcrop generally stands out prominently on account of the hardness of the rock, could be traced, it was said, almost continuously from Lion Hill on the north to the southern end of the range. The lithological character of the Gold ledge made it much more difficult to trace, it being marked at the outcrop often by only a slight ocherous appearance in the rock, the gold being under no circumstances visible. Hence there was not the same certainty felt as to its character and extent beyond the deposits already

[1] In justice to Mr. Hills it should be said that his examination was made in the winter, when the snow lay deep on the mountain slopes, rendering observation difficult outside of the mines and hiding the details of much of the geology.

The main points of difference in the conclusions arrived at by the respective observers may be summarized as follows:

1. Mr. Hills considers that Mercur is situated at the crown of a quaquaversal uplift, such as might have been produced by the intrusion below of a body of eruptive rock.

2. Certain cherty zones in the limestone are thought by him to have determined the location of the ore deposits, on the ground that the abundance of chert indicates purification of the limestone by the separation of the silica, and that the mineralizing solutions would have acted more readily upon a pure than upon an impure limestone.

3. The mineralizing solutions are supposed by him to have come from below, and to have ascended through vertical channels now chiefly occupied by veins of heavy spar.

From the present investigations it does not appear that the slight upward bulge in the strata observable in the Mercur Basin constitutes a quaquaversal. as there is no perceptible pitch of the sedimentary series as a whole to the northward, and such variations from the regular NNW. strike as are found are quite local and are due to local causes.

The presence of chert in the limestone is not believed to have had any effect in determining the location of the ore; many other horizons which contain quite as much chert as that carrying the gold ores show no sign of mineralization.

While the mineralizing currents are believed to have been ascending, and some of the vein materials undoubtedly came up through veins now filled with barite, the filling of these veins is believd to have occurred before the introduction of the gold, and hence the latter had no necessary genetic dependence on the barite.

being mined, and one of the important objects of this investigation was to discover some characteristic by which it could be more readily traced.

After the completion of the preliminary part of this work, which consisted in constructing a topographical map of the basin upon which the geological outlines could be accurately delineated and in making a general and comprehensive examination of the geology of this and immediately adjoining districts as well as of the principal mines, the writer found it necessary to return East. Upon his assistant, Mr. J. E. Spurr, there devolved the entire labor of working out in detail the minutiæ of the geological structure of the ore bodies and their relations to the eruptive rocks, of which only the larger bodies at the northern and southern limits of the basin respectively had thus far been recognized. The results of his field observations, which were made with the utmost zeal and geological acumen, and of the laboratory and microscopical examinations which supplemented them, together with his more theoretical deductions with regard to the origin and mode of formation of the precious-metal deposits of the region, are given in the following pages In justice to their author, and in order that he may receive due credit as well as assume entire responsibility for such of his views as are peculiar to himself, they are given in his own words.

His first important discovery was that certain seams or beds of shale-like material, which in the mines generally form the roof of the ore bodies, and both there and on the surface often have very little in their outward appearance that suggests an igneous origin, are in reality thin, highly altered sheets of a white porphyry, called, from the hill on which its largest outcrop is found, Eagle Hill porphyry. No fewer than three of these very thin sheets, one above the other, were traced by him in the ore-bearing zone. It was often the case that field observations could not determine with certainty whether a given portion of the material was of sedimentary or igneous origin, and then recourse was had to microscopical and chemical examinations. It was found that, while these sheets preserve a general parallelism to the stratification, they are by no means strictly confined throughout their entire extent to one and the same bedding plane, but at times cross from one to another, generally at a low angle.

CONCLUSIONS.

The main conclusions arrived at by Mr. Spurr with regard to the ore deposits may be briefly stated as follows:

There have been two distinct periods of mineralization in this district; during the first what is called the Silver ledge ore was formed, and during the second the minerals of the Gold ledge were deposited. In each period the minerals constituting the ore were deposited mainly along the lower contact of a porphyry sheet, where a somewhat porous or brecciated zone had been formed by the intrusion of the igneous

material, which the mineralizing solutions reached through fractures or fissures extending downward from the respective sheets.

The principal vein materials of the Silver ledge are silica, barium, antimony, copper, and silver. They are assumed to have been brought up by ascending hot solutions, the metals in the form of sulphides, the barium as sulphate. They were deposited for the most part in the contact zone below the lowest of the three porphyry sheets, and to a limited extent above this sheet. Throughout the whole zone the limestone is almost entirely replaced by silica. The fissures through which the minerals are supposed to have come up have since been filled with calcite.

The principal vein materials of the Gold ledge are realgar, cinnabar, and pyrite, with gold, which was probably deposited as telluride. With them are associated barite and calcite, presumably of earlier formation, together with gypsum and other secondary minerals. The deposits at this horizon are found mainly at the intersection of certain zones of northeast fractures with the lower contact of the middle of the three porphyry sheets, and reach a thickness of 20 feet or more, thinning out to little or nothing away from the fracture fissures. Some of the principal fissures are still open, and show no evidence of filling or erosion by circulating waters. These fractures cut across the Silver ledge, and as a rule do not extend above the Gold ledge.

These are facts of observation. Reasoning from them and others which are given in detail in his text, Mr. Spurr concludes, with regard to the more remote and hypothetical origin of the vein minerals: First, that the minerals of the Silver ledge were pressed out of the cooling body of porphyry with the included water and brought to their present position in aqueous solution; that the characteristic minerals of the Gold ledge, however, were, at an entirely later period, brought to their present position through the system of northeast fractures by fumarolic vapors proceeding from some unknown body of igneous rock which did not reach the surface.

According to these assumptions and those already made with regard to the age of the igneous rocks, the Silver ledge mineralization must have taken place just before or after the Jurassic movement. On general structural grounds it would seem more probable that it occurred after the movement, but if the water which carried the minerals in solution was exuded from the eruptive magma during its consolidation, as Mr. Spurr thinks, this must necessarily have taken place before the plication, as, had the magma been still partially liquid at this time, it would have been forced into all the small cracks and fissures near by that would have been created during this movement.

The period of the Gold ledge mineralization, since it was separated from that of the Silver ledge by the formation of the northeast fractures, must have been later than Cretaceous or as late as Tertiary. Its possible connection with or dependence upon an unknown body of

recent eruptive rock is too remote to justify an attempt to fix the period with more definiteness. The theory that metallic minerals have been brought into ore deposits by fumarolic vapors, which is the one generally entertained by geologists of the French school, is one that the present writer is not inclined to look upon with favor, though he admits the logic of Mr. Spurr's reasoning with regard to the deposits under consideration.

The more practical and tangible conclusions which may be derived from this investigation are, that in searching for gold ore in this district it is necessary, first, to learn to recognize and identifiy the porphyry sheet in the field in its many and varied forms of alteration, and then to follow that, rather than any given bed in the limestone series; second, having traced the Gold ledge porphyry sheet, one should follow the intersection of this sheet with the principal zones of northeast fracturing, and prospect the ground downward along these intersections and in their vicinity.

It may further be remarked that it is probable that the oxidized ores susceptible of ready reduction by the cyanide process will be found to be confined to a zone of rock within a very limited distance from the surface, and that explorations in depth will soon reach sulphide and telluride ores, which may have to be smelted. It is, however, fair to assume that these ore bodies are likely to increase in size and richness with depth, and that sulphide ores may be found which are sufficiently rich to be mined at a profit, in spite of the difficulty of their reduction.

CHAPTER I.

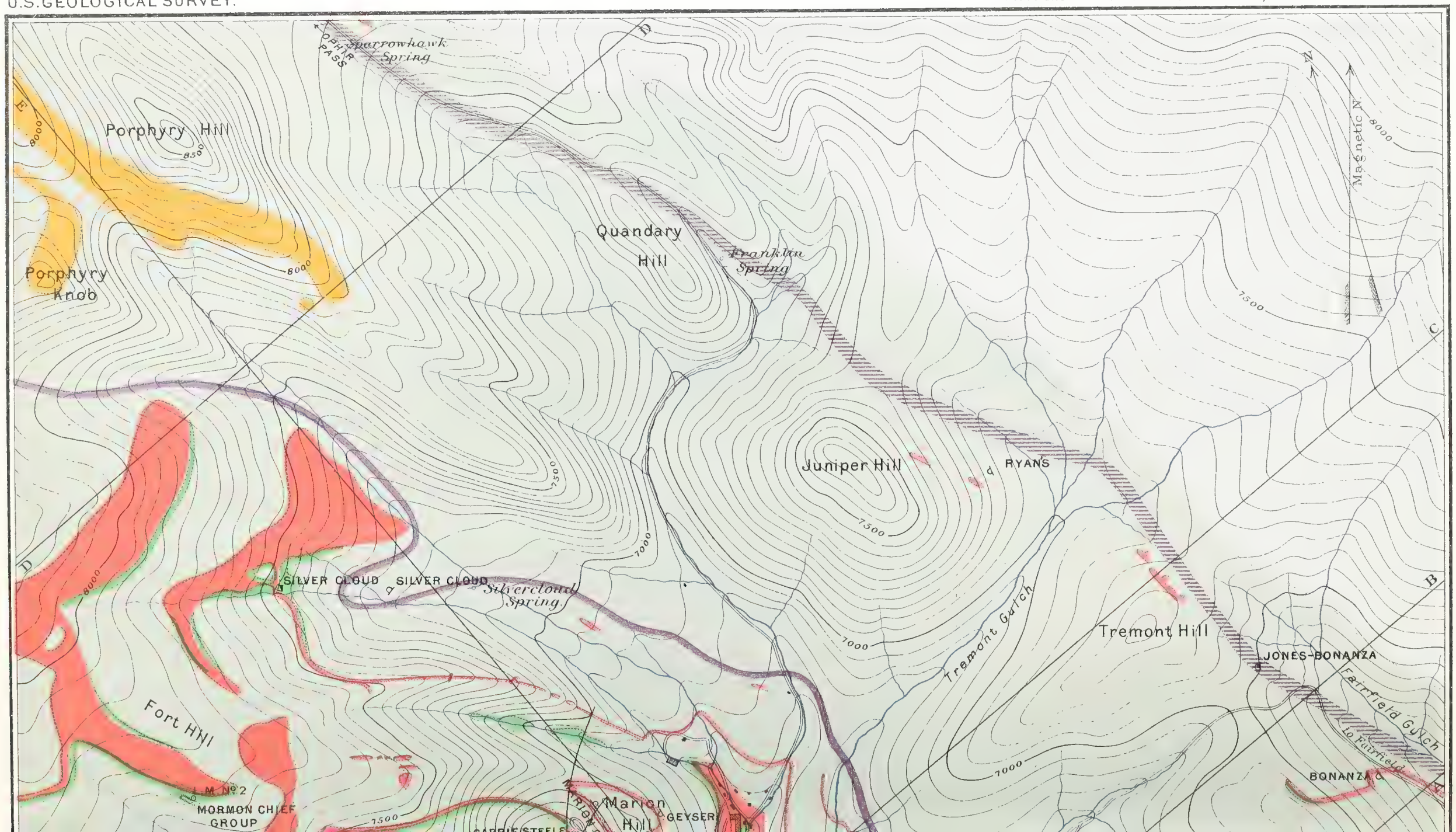
THE MERCUR DISTRICT.

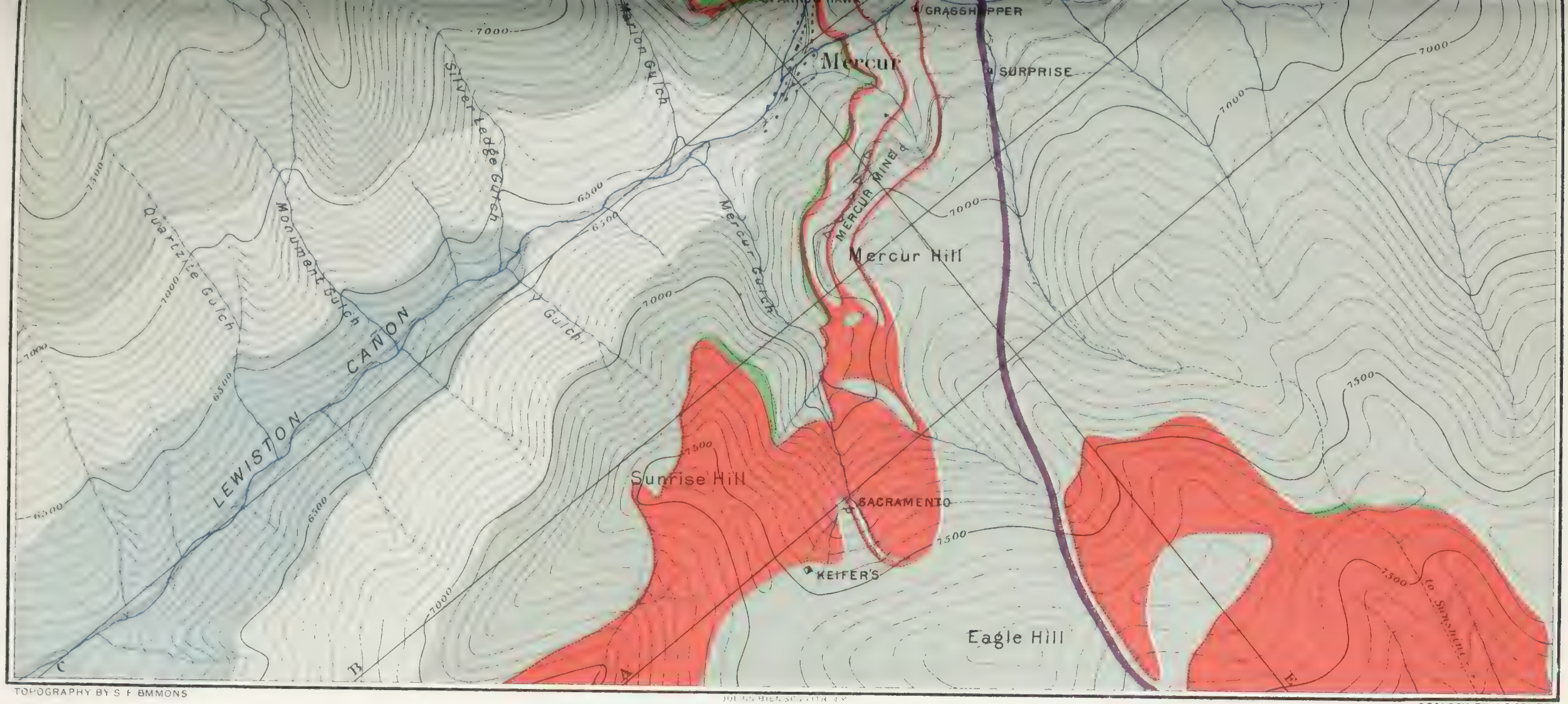
At the present time the actually productive region in the immediate vicinity of Mercur lies within a space a mile square, including the Mercur and the Marion mines and the workings immediately surrounding them. In order to study the geology of these deposits an area of 6 or 7 square miles has been mapped. The town of Mercur and the Mercur deposits are nearly in the center of this area, which embraces almost the whole of the basin in which they lie. Not only the gold-bearing districts but also the silver-bearing portions, which have apparently a much more extended distribution than the gold, are included in this basin. To the north this area runs, with no sharp geological boundary, into the districts of Lion Hill and Ophir, while to the south a series of explorations extends to Sunshine. At Sunshine, a mine lying about 4 miles south of Mercur, there are deposits of gold ore which appear to be essentially like those of Mercur, but on account of its comparatively slight development this district has not been included on the map. The Sunshine and the Mercur ores are mineralogically and genetically so closely related as to form a class by themselves, being, so far as at present known, quite distinct from those of the other districts of the Oquirrh Mountains.

STRUCTURE.

In the Mercur Basin there are exposed, within a distance of 5 or 6 miles, sedimentary beds to a thickness of about 12,000 feet. Their structure is very simple. A single anticline with northwest axis covers the entire district shown on the special map. The axis runs through the corner of the mapped tract, west of the town of Mercur, so that nearly all of the rocks shown on the map belong to the northeastern limb of the fold. The null point in the fold, where the rocks lie horizontal, is seen in a section afforded by Lewiston Canyon. In this canyon, about a mile and a half southwest of Mercur, the rocks change from their usual northeast dip and become horizontal, then pass into gently southwesterly dipping strata. Going southwest, the dip gradually steepens, but within a few miles the rocks pass under the Pleistocene formations of the plain. At this point they dip 15° or 20° W.

Going northeast up the canyon from the axis of the anticline, the dip gradually steepens again, and at the town of Mercur it averages about 20° E. Going further on in the same direction with the dip, and


Sparrowhawk Spring
OPHIR PASS
Porphyry Hill
Porphyry Knob
Quandary Hill
Franklin Spring
Juniper Hill
RYANS
Magnetic N
Silverclouds Spring
SILVER CLOUD
SILVER CLOUD
Tremont Gulch
Tremont Hill
JONES-BONANZA
Fairfield Gulch
to Fairfield
BONANZA
Fort Hill
L.M. No 2
MORMON CHIEF GROUP
Marion Hill
GEYSER
7500
7000
8000
8500



UPPER INTERCALATED SERIES

GREAT BLUE LIMESTONE

BLACK SHALE (Chief Water Bearing Zone)

BLACK SHALE (Lesser Water Bearing Zone)

LOWER INTERCALATED SERIES

LOWER LIMESTONE

QUARTZ PORPHYRY
BIRDSEYE PORPHYRY
EAGLE HILL PORPHYRY

CHERT (Silver Ledge)

Indicates Shaft
Indicates Tunnel

GEOLOGICAL MAP OF THE MERCUR BASIN

Scale

1500 0 1500 3000 4500 FEET

Contour Interval 50 Feet.

crossing the basin toward the steeper mountain side, the dip increases rapidly and somewhat regularly for over a mile; then there is a sudden steepening, so that it passes, within a short distance, from an average of 25° or 30° to about 60°. From the line of this steepening, which is ordinarily well marked all along the line of strike in the district especially examined, the dip is very uniform up to the top of the mountain ridge which separates Mercur Basin from Pole Canyon, averaging about 60°.

Besides this anticline, there are no large disturbances worthy of note. There are some very small irregularities, such as must occur everywhere, and some of these will be noticed further on; but on the whole the structure is as simple an anticline as is generally found. The relative depression of the Mercur Basin, as compared with the higher hills which stand to the north and to the south, along the line of strike, causes the outcrop of the strata, in passing through the basin, to deviate from a straight line in the form of a distinct bulge to the northeast. This appearance is not indicative of any great irregularity in the strata, but is due simply to the recession of the rocks along the dip with the greater erosion. The longitudinal section (E-E, Pl. XXVII) shows that there is actually very little irregularity along the main axis of the fold.

LOWER BLUE LIMESTONE.

The lowest horizon in the district covered by the Mercur map is seen in Lewiston Canyon, under the arch of the anticlinal fold. This is a dark-blue, at times semicrystalline limestone, carrying Lower Carboniferous fossils. It forms a type which is ordinarily distinct from the other limestones of the district by reason of its somewhat darker color, as well as of the granular appearance which it derives from the coarser grain and the typically semicrystalline condition. It is only in Lewiston Canyon that this lowest horizon is exposed within the district shown on the map. Going down the canyon from Mercur, it is met at about three-quarters of a mile from the town, rising up in the bed of the canyon with gentle northeasterly dip. It continues to form the bed of the canyon till very near the point where the canyon opens out upon the plain. At this point the slight southwestern dip has brought it down again, and it disappears below the overlying beds. In the middle of the exposure, directly in the anticlinal arch, a thickness of about 200 feet of this limestone is shown in the walls of the canyon. The bottom, however, is not seen, and so no statement in regard to the total thickness of the horizon can be made. A typical locality of this rock is at the mouth of Quartzite Gulch; this is also one of the best localities for fossils. Specimens collected at this point have been found by Mr. C. H. Schuchert to be of Lower Carboniferous age.

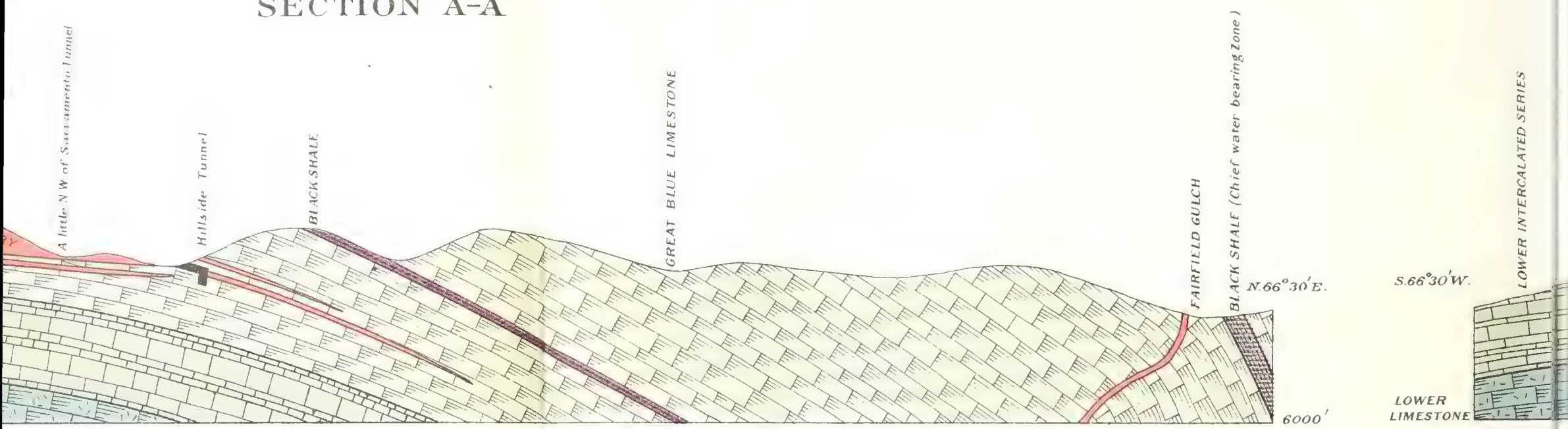
LOWER INTERCALATED SERIES.

Directly above the lower limestone comes a series of alternating thin beds of limestone and calcareous sandstone, with rocks representing various stages between the mainly siliceous and the purely calcareous sediments. This series is about 600 feet thick. The thickest bed of sandstone, which has a thickness of about 100 feet, is at the bottom of the series. From this bed to the top of the series there are frequent alternations of siliceous and calcareous sediments, so closely following one another and presenting such numerous transitions from the one to the other as to show that the entire series was deposited at a comparatively uniform depth, just on the border between detrital deposits and those of organic origin. Nearly all the sandstones are more or less calcareous, and the limestones are usually siliceous.

The contact between the limestone and sandstone beds is, however, usually distinct, showing a decided, if only temporary, change in the conditions of deposition. This distinct contact does not necessarily imply any great change of depth, of currents, of supply of material, or of other conditions. The series was deposited, as before stated, at the critical point of sedimentation—the boundary line between the arenaceous detrital deposits and those calcareous sediments which derive only a small part of their material directly from the degradation of the land. From its nature, and from the complexity of the minor conditions which influence it, this boundary is in no case stable, but must continually swing to and fro irregularly, even when the sea-bottom maintains the same distance from the surface. The closely alternating beds of this series can not, therefore, be taken as necessarily indicating repeated minor oscillations of the sea-bottom during their deposition.

This is illustrated by the fact that the individual smaller beds are not permanent, even over small horizontal distances. Two parallel detailed sections were made up the sides of Lewiston Canyon, where the steep, bare walls are particularly favorable to accurate observation. These sections are about three-quarters of a mile apart, and since the beds lying between them are very nearly in a horizontal position, the distance between the sections is about the same as at the time of deposition. Yet in the more southwesterly section the thickness of this intercalated series seems markedly greater than in the northeastern one. The beds of sandstone are rather thicker, more numerous, and separated by thicker beds of limestone. In the northeasterly section fourteen distinct beds of sandstone were counted; in the southwesterly one, nineteen. From this it will be seen that there is no possibility of finding a perfect agreement between these two localities, and that in the intervening distance some of the sandstone beds of the one section must thin out and be replaced by the limestone which occurs in the other section. This inference is corroborated by actual observation in

SECTION A-A



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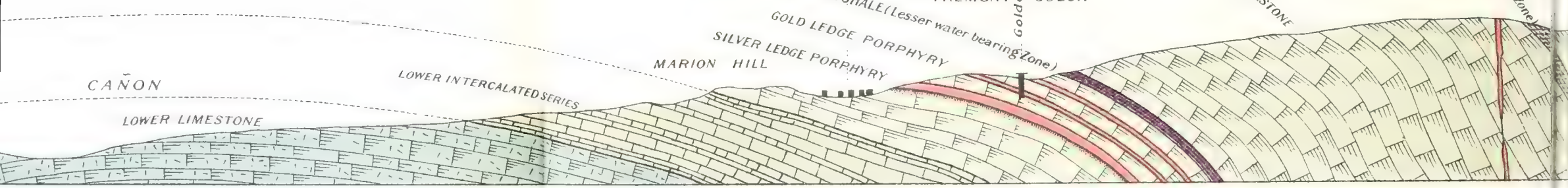

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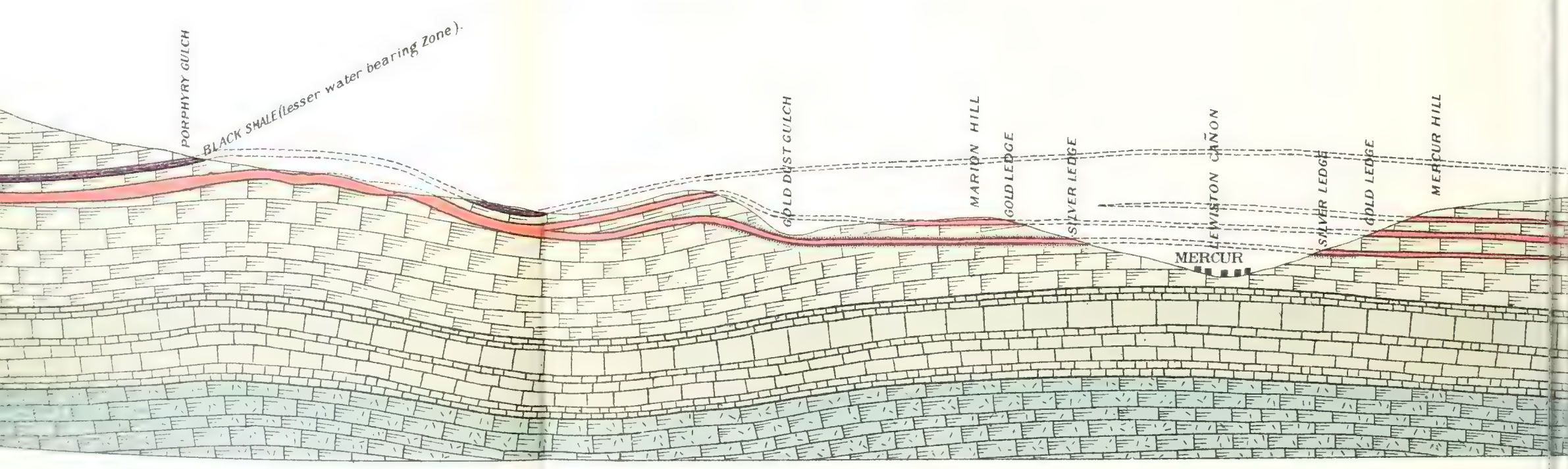

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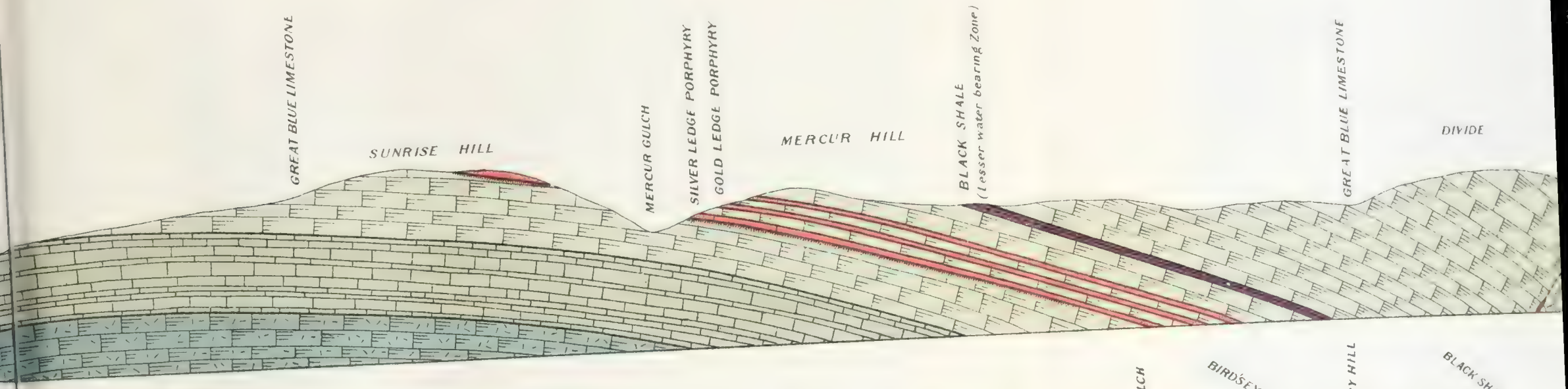

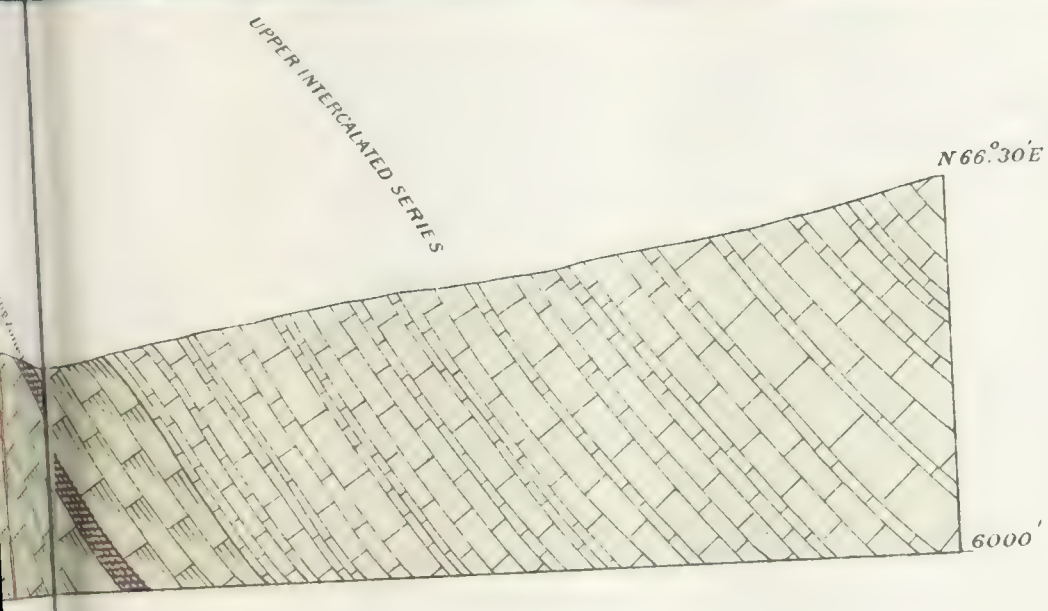

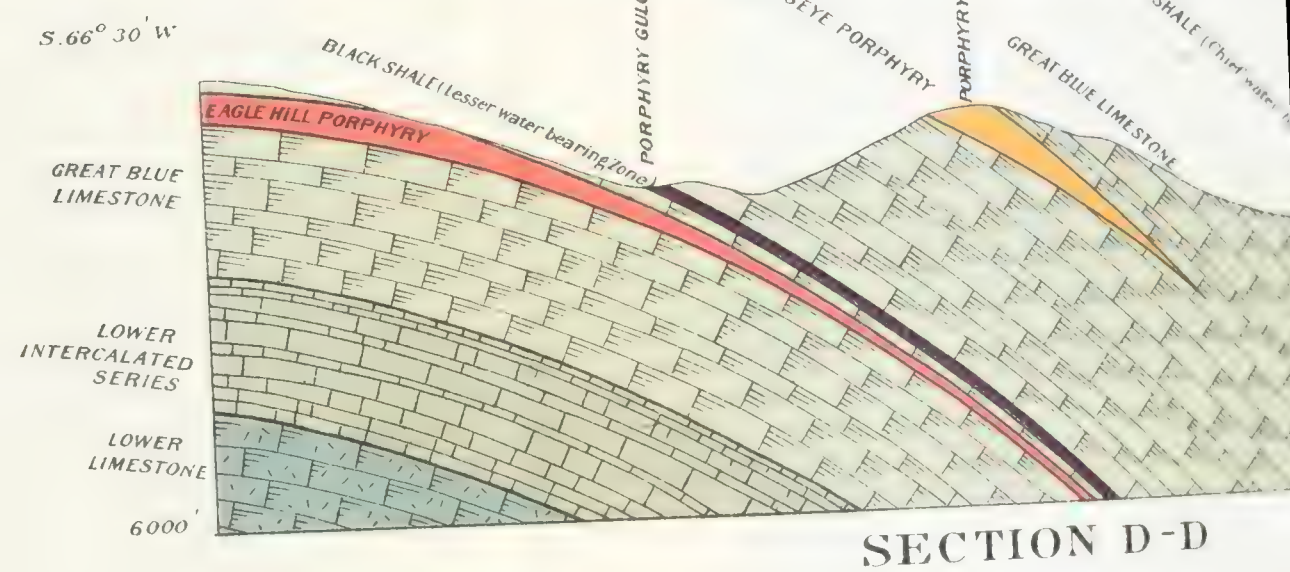

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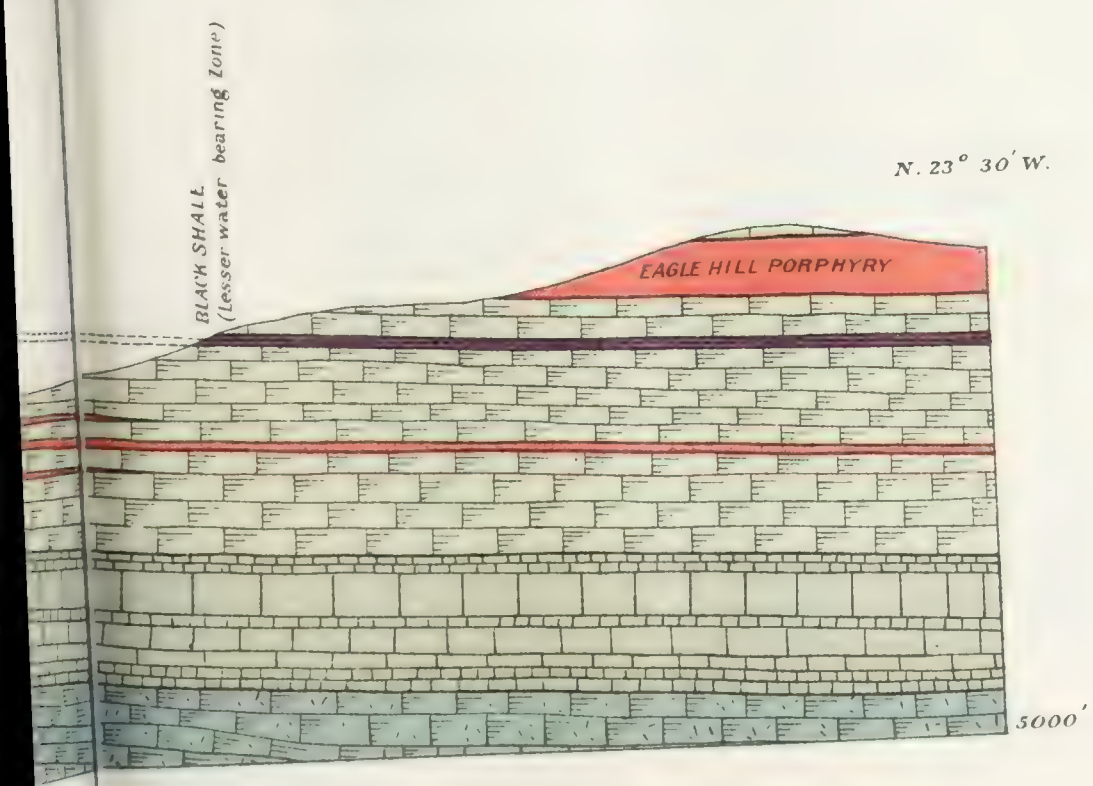


GEOLOGICAL SECTIONS OF MERCUR BASIN

BASED ON THE MERCUR BASIN MAP.

VERTICAL AND HORIZONTAL SCALE

1200 0 1200 2400

the field. In the canyon there are places between these two sections where beds of sandstone thin out and are replaced by limestone; and this is so frequent that it is a question whether the exact equivalent of any of the thinner beds of the one section can be found in the other. Yet in a general way the equivalence of the conditions in the two localities may be inferred from the relation of the beds. At the bottom of the northeast section, and near the bottom of the other, is the thickest bed of sandstone in the series, measuring about 100 feet in the one and 120 feet in the other. This bed may easily be traced along the wall of the canyon for the whole distance of the outcrop of the series.

In color the sandstone is generally grayish-green, sometimes reddish. It has a distinctly granular texture and conchoidal fracture, and the detrital grains of quartz are usually visible to the naked eye. In the hand specimen it has all of the usual characteristics of quartzite, except that the application of acid produces a slight effervescence, indicating the presence of lime carbonate. Under the microscope the rock is found to be rather uniform, consisting of rounded grains of quartz in a cement of cryptocrystalline calcite. Ordinarily the sand grains do not touch, but are quite isolated; and the character of the cement, which is exactly like that of the pure limestones, shows that calcite and quartz were deposited simultaneously, and that there has been no considerable alteration since the deposition. In rare cases, where the sandstones have been affected by the silicification attendant upon the mineralization, the rounded grains have become faceted, and then appear as quartz crystals, interlocking or embedded in the fine-grained limestone.

The limestone varies greatly in nature, as might be expected from the varying conditions of deposition. The dark-blue, semicrystalline rock, which has been described as occupying a position inferior to the Intercalated series, has not been seen at a higher horizon. The most frequent type in the Lower Intercalated series is dark gray-blue to slate-gray in color; usually fine-grained and compact in texture. This variety is not crystalline, and generally breaks with a smooth, conchoidal fracture. The rock is the typical limestone of the district, being essentially the same as that which overlies the Lower Intercalated series. It contains frequent concentric, lenticular, or irregular chert concretions, which are conspicuous on weathering, so that the rock very often takes on a rough appearance. The color of the weathered rock varies from light-brown to light-gray or nearly white, depending upon the varying but always small content of iron, while the lower semicrystalline limestone, on account of its great purity, typically retains its dark-blue color on weathering.

A very fine-grained limestone, breaking with a smooth, conchoidal fracture, forms a peculiar type which appears to be confined to this series, since it has not been met with in its typical form anywhere else in the district. It is homogeneous and apparently very pure, being translucent, and has a beautiful, uniform, dove-gray color, both in the

fresh state and on weathering. It has all the characters of lithographic stone, but specimens uniform enough to be of commercial value were not noted. This limestone forms a number of thin beds, never exceeding 15 or 20 feet in thickness. It is usually found separating two beds of sandstone.

A single bed in the Lower Intercalated series consists of a snow-white, completely and coarsely crystalline limestone. The bed examined was between 1 and 2 feet in thickness, and was found only in one of the Lewiston Canyon sections. Mineralogically this rock seems to be like a very pure marble, but the crystalline structure in this case can not be due to any pressure or contact-metamorphism subsequent to deposition, for the bed lies between two beds of the translucent, dove-gray limestone just described, and a large fragment of a coral in a comparatively unaltered condition was found in it. This peculiar limestone is also found in one or two very thin beds in the Upper Intercalated series, a similar but vastly thicker series, which forms the uppermost of the rocks of the Mercur Basin. In the pure limestones, however, it has not been met with. It is evident, therefore, that both this and the fine-grained, dove-gray rock owe their origin to peculiar conditions of sedimentation, and from their association with the Intercalated series it is probable that these conditions were simply a peculiar modification of those which obtained for the deposition of the entire series, and were contrasted with those which governed the deposition of the thicker and more ordinary limestones. It is quite possible that both of these peculiar limestones may be due to direct chemical precipitation.

GREAT BLUE LIMESTONE.

Next above the Lower Intercalated series comes the formation which occupies the most of the Mercur Basin. This is a comparatively uniform, massive limestone, of a dark gray-blue color, nearly like that of the Lower limestone. It breaks with a rough, conchoidal fracture; on weathering it becomes pulverulent, greenish or pinkish, or nearly white. From its color one might suppose that it is impure, but an analysis of a typical specimen shows that in reality it is very pure, containing only a small amount of insoluble matter. It is an entirely calcareous limestone, being quite free from magnesia; the color is due to the presence of a small amount of organic material. Usually the outcrop is very fresh, the changed material being carried away as fast as produced, but in many places the alteration products have accumulated, so that the rock is more or less altered to a depth of many feet. A notable instance is seen in the cut for the railroad, just southeast of the Surprise shaft, where the rock has been altered to a light-gray powder for a depth of 20 feet or more, apparently by surface agencies alone.

The upper limit of this rock, which may be called the Great Blue limestone, is not distinct, for it passes gradually into the series next

MERCUR BASIN, LOOKING NORTH.

Marion Hill in left foreground

higher up. Its thickness, therefore, may be variously estimated, according as the upper boundary is defined; the maximum, however, is about 5,000 feet.

SHALE BEDS.

There are certain variations in the nature of the generally uniform sediments which have enough character and persistence to be noticed. Most marked among these geologically, and most important economically, are the belts of black carbonaceous and calcareous shale. These are two in number, one situated near the bottom and the other near the top of the Great Blue limestone. The upper one is the larger and the more persistent in regard to its characters. It lies about 1,000 feet from the top of the Great Blue limestone, if the latter is considered in its maximum thickness, as estimated above; but if it is considered in its minimum thickness, then the shale itself may be held to indicate its upward termination. The shale lies in a strike valley which evidently owes its existence to the more ready erosion of the shale beds, as compared with those of the harder limestones. The thickness of the belt is somewhat more than 100 feet. These shales can not be considered as typical detrital sediments; they are simply phases of the limestone. In places, especially where they have been acted on by running water, they are soft and have no great cohesion; in other places on the same horizon the rock is so hard and contains so much lime that it deserves rather the name of a shaly limestone, if considered without reference to the other localities. Specimens from this shale belt nearly always effervesce with acid. The carbonaceous matter is varying in amount, but never very great. In the Jones-Bonanza shaft, which cuts the shale at a point southeast of Tremont Hill, near the divide between Mercur Basin and Fairfield Canyon, parts of the shale contain coal, scattered thickly throughout it in the form of small seams and layers and as brilliant particles. The lustrous appearance thus given makes the rock seem at first sight to be a useful coal; but it is found that nearly every part will effervesce with acid, and if a piece be burnt the incombustible residue, consisting chiefly of lime, is found to form the larger part of the rock.

The lower shale belt lies about 2,500 feet below the upper one, and about 1,000 feet above the bottom of the Great Blue limestone. Its characters are essentially the same as the upper, but are less emphasized; for, as it is not so thick, its relation to the pure limestone on both sides is closer. This shale belt averages about 25 feet in thickness, but it is variable and often becomes shaly limestone, so that it is not always possible to identify it exactly. These two shale belts carry springs which furnish the entire water supply of the Mercur district.

Just above the larger shale belt are usually thin-bedded, somewhat shaly limestones, which are transitional between the shale and the massive blue limestone. These rocks are distinguished by the thin plates into which they split on weathering, and by the brighter reddish

and greenish color of the slightly weathered specimens. There is no sharp boundary between the shaly limestones and the rocks above and below.

UPPER INTERCALATED SERIES.

Above the upper shale belt the rocks begin to contain arenaceous layers, separated by very thick beds of pure limestone. At a distance of about 1,000 feet above the top of the shale these sandstone beds become so common as to mark the lower limit of a new lithological series, the Upper Intercalated series. This reproduces on a larger scale the characters of the Lower Intercalated series. The rock types are nearly the same, but the individual beds are thicker and farther apart. From the bottom of the series to the top of the ridge there are probably about a dozen beds of sandstone, each of which has a thickness of 100 feet or more; yet in places the sediments seem to alternate even more closely than in the lower series. Many of the beds present for considerable distances a complete intermediate stage between sandstone and limestone, and in places layers of mainly calcareous sediments alternate very uniformly with layers which are mainly arenaceous, each layer being only a few inches thick, and the alternation being many times repeated. The thickness of this Upper Intercalated series, as estimated from its base to the summit of the ridge which divides Mercur Basin from Pole Canyon, is 5,000 or 6,000 feet. This, however, is not the top of the series, for the rocks preserve their northeasterly dip for a considerable distance down the other side of the mountain into Pole Canyon before beginning to rise again on the other side of the syncline. The total thickness, therefore, must be upward of 6,000 feet, and may be as much as 10,000 feet.

This series occupies the northeast corner of the tract shown on the detailed map, where a thickness of over 4,000 feet of the strata appears.

RÉSUMÉ.

It will thus be seen that the structure of the rocks of the Mercur Basin is simply that of one limb of an anticlinal fold, the beginning of the other limb being in the southwest corner, as seen near the mouth of Lewiston Canyon. Lithologically this conformable series may be divided into (1) the Lower Blue limestone, which occupies the bottom of the canyon, and of which there are exposed, under the arch of the fold, about 200 feet; (2) the Lower Intercalated series, consisting of interbedded limestones and calcareous sandstones, having a thickness of about 600 feet; (3) above this a very thick blue limestone, which has been designated the Great Blue limestone, and which has a thickness of about 5,000 feet. This limestone holds the beds of shale which furnish the water supply for the district, and is also noteworthy for containing in its lower portion the ore horizons. Above the Great Blue limestone comes (4) the Upper Intercalated series, consisting of

interbedded limestones and sandstones, like the lower series, but on a larger scale. Measured to the top of the ridge, which is the margin of the basin, this series shows a thickness of 5,000 to 6,000 feet. There is thus exposed in that part of the Oquirrh Mountains which we have called the Mercur Basin a total thickness of nearly 12,000 feet of strata.

AGE OF THE STRATA.

Fossils were collected from the beds in the Mercur Basin at various points, so as to represent as well as possible the entire series from the Lower Blue limestone to the Upper Intercalated series. These were submitted to Mr. Charles Schuchert, of the United States Geological Survey, who found them all to be of Carboniferous age. According to his report, the Lower Blue limestone and the Lower Intercalated series are in the Lower Carboniferous, while the Upper Intercalated series is probably in the Coal Measures. The boundary between these two divisions can not be closely defined. It may be in the middle or the upper part of the Great Blue limestone, or, more probably, at the top of it. The fossils form a gradually changing series, which begins somewhere above the base of the Lower Carboniferous and seems to terminate in the Upper Carboniferous.[1]

ERUPTIVE ROCKS.

In the Mercur district there are two distinct varieties of closely related eruptive rocks, which form sheets or small dikes in the Great Blue limestone. Both these rocks belong to the class of quartz-porphyries, although they are very dissimilar in appearance.

EAGLE HILL PORPHYRY.

One of these varieties is found in greatest thickness and freshest condition in the vicinity of Eagle Hill, on the divide which separates the Mercur Basin from Sunshine and the southern end of the range. This rock in its freshest condition is nearly pure white, with a grayish, brownish, or sometimes pinkish tinge; it is compact and fine grained, and breaks with a conchoidal fracture and a rough texture. Small phenocrysts of quartz, feldspar, and biotite may often be observed, though they are never conspicuous; rarely the thin plates of biotite become nearly a quarter of an inch across.

A specimen of fresh rock shows under the microscope a finely microcrystalline ground-mass, in places made up of very small spherulites, which occasionally grade into a micropegmatitic intergrowth of quartz and feldspar. Lath-shaped microlites of feldspar are very common, but the main part of the ground-mass is not coarse enough to render the component minerals distinguishable. Phenocrysts are rare, but are fresh when found. They consist, so far as observed, of quartz, biotite,

[1] Of a series of fossil bryozoans and brachiopods from the lower shale belt, recently received, Mr. Schuchert says: "They are of the Osage age (Burlington-Keokuk), of the Mississippian series."—S. F. E.

and orthoclase feldspar. The quartz is in crystals or irregular grains, which show corrosion by the magma previous to the consolidation of the rock. The feldspar has crystal outlines, often rounded by corrosion, and shows no decomposition. The biotite is dark colored and strongly pleochroic; along its cleavage cracks some of the iron has separated out as oxide.

Except where the beds are thickest, the porphyry is usually considerably decomposed, and the thinner the sheet the more, as a rule, has it suffered from contact with atmospheric or other disintegrating agencies. On weathering, the rock loses cohesion and becomes a compact, very fine-grained, chalky mass, so soft as to be easily impressed with the finger nail, or finally a loose powder. The weathered rocks are usually of a cream-yellow color, but they are often stained in a variety of shades—red, yellow, greenish-gray, or nearly black.

The Eagle Hill porphyry seems to be split up chiefly into two principal sheets, which are well exposed on the sides of Eagle Hill. Both are in a general way parallel to the bedding of the limestone, so that they are true sheets; in places, however, the boundary cuts across the bedding at a considerable angle, which sometimes is as much as 90°. In such cases, and in places where only a small part of the contact was observed, it has been supposed that the porphyry is in the form of dikes. Observation of the contacts at special places is very confusing and unsatisfactory in settling this question, but when a continuous contact is mapped and plotted over a considerable distance the true relation of the limestone to the porphyry is very clearly seen.

Since the hills around Mercur are not covered by drift or alluvium, it is comparatively easy to trace continuously the line of contact of the eruptive with the sedimentary rocks. If, as is often the case, the actual boundary can not be seen, it can generally be identified by fragments which lie on the surface, and which are found usually to correspond pretty closely with the solid rock below. In the weathered rock the limestone chips are of the typical dark-blue color, while those of porphyry are cream-yellow, sometimes brown or green; and on a bare hillside the line separating the two can be rapidly traced. If the hill is steep, however, the formation of a talus may hide the contact for a space.

In the Mercur Basin map the uppermost of the two principal sheets is shown east of Eagle Hill on the ridge south of Mercur. The top of the knob next east from Eagle Hill is of limestone, and the porphyry forms a broad belt on its sides. This sheet is probably between 250 and 300 feet thick, but it dies out rapidly, and to the northwest the outcrop does not descend from the hill, but is replaced by limestone. It is not represented, therefore, in any but the extreme southern part of the map, and does not pass through the basin.

The second sheet, which is estimated to be stratigraphically about 700 feet below the first, is found in its greatest thickness and with its rocks

MERCUR BASIN, LOOKING SOUTH.

Mercur Hill in right foreground

in the freshest condition on the spur between Eagle Hill and Sunrise Hill. The greatest thickness exposed here is probably upward of 300 feet, but it seems to thin with great rapidity to the north and east, and to split into several small sheets. Owing to the northeast dip, these thin sheets are well exposed only in the places of deepest erosion,—in this case in the lowest part of the Mercur Basin, at the head of Lewiston Canyon. Here, owing to their small thickness, they are much decomposed; they are also intimately connected with the ore deposition. There are here three small sheets, averaging about 10 or 15 feet in thickness. On the other side of the basin they seem to unite again, and the porphyry becomes temporarily thicker than in the basin. Yet it is probably nowhere more than 100 feet thick, and usually it is much less. The same general sheet of porphyry has been traced to the northern side of Lion Hill, at a point overlooking Ophir Canyon.

On the southern side of Eagle Hill the upper sheet occupies a considerable area (see map, Pl. XXV, p. 360); the lower sheet seems to be split up into two thin sheets, one of which runs around and joins the upper body, while the other persists in the bottom of Sunshine Gulch, past the Glencoe and the Sunshine mines, till it disappears in the foothills south of Sunshine. Nearly all these outcrops are on the northeast limb of the anticline, where the rocks dip to the northeast.

The arching of the fold causes the outcrop to describe a curve on the southeast side of Lewiston Canyon. Here the porphyry can be traced rising up above the top of the canyon wall, till with the new dip to the southwest it comes down to the bottom of the canyon again at its very mouth. On the other side of the canyon there is a part of the corresponding curve, but it does not appear to be completed, so as to join itself with the first. This may be due to a local disappearance of the sheet.

As before stated, the porphyry has its greatest development around Eagle Hill, and it seems probable that somewhere in this vicinity exists the channel through which it came up from below. The lower sheet is thickest on a line running directly from Eagle Hill to Lion Hill, and appears to thin gradually from the former toward the latter, though the erosion of the deeper valleys has removed it from much of the intermediate region. Northeastward from this line it thins rapidly, and to the northwestward it thickens.

BIRD'S-EYE PORPHYRY.

The other variety of porphyry, called by miners and explorers Bird's-eye porphyry, is exposed on the area of the Mercur Basin map only in the northwest corner. It forms part of two conspicuous eminences, which have been called Porphyry Hill and Porphyry Knob. This rock does not in any way resemble the porphyry just described. In its freshest condition its general color is gray. The porphyritic crystals are well developed, and make up a large part of the bulk of the

rock. They consist of light-gray feldspars of rather uniform size, the larger varying from an eighth to a quarter of an inch in diameter; also regularly disseminated biotite in black hexagonal prisms about an eighth of an inch in diameter, and occasional quartz crystals. These, with many smaller phenocrysts, are set in a greenish-gray ground-mass. On decomposition, the ground-mass assumes a deep olive-green color, which becomes brownish in places; the feldspars become whiter, so that they stand out more sharply from the rest of the rock, and the mica assumes a greenish-bronze color. The process of alteration of this rock is as different from that of the Eagle Hill porphyry as are the two rocks in appearance. In the beginning of the process the Eagle Hill variety breaks up into small, sharp fragments, which become dislodged and lie in great numbers on the surface above the solid rock. As disintegration proceeds the rock is finally reduced to the pulverulent state. In the Bird's-eye porphyry, however, this is not the case. The alteration proceeds gradually throughout the rock, as it does in the disintegration of granites. The rock does not split or shell, but remains firm till the process is far advanced; hence, by the time it loses its cohesiveness it is so much decomposed as to be ready to form soil. When the rock crumbles the minerals which make up the porphyritic crystals can still ordinarily be distinguished.

On the edge of the Mercur Basin the Bird's-eye porphyry consists of a single sheet, conformable with the stratification and with the sheets of Eagle Hill porphyry. The horizon of the two porphyries is in a general way about the same, although near Porphyry Hill the sheet of the Eagle Hill variety is several hundred feet lower down than the Bird's-eye porphyry. The latter occupies the summit of Porphyry Knob, where it has a columnar structure, which is developed by weathering. Between Porphyry Knob and Porphyry Hill, erosion has worn down through the sheet and revealed the limestone beneath. The southwest slope of Porphyry Hill stands at right angles to the dip of the strata, and the full thickness of the porphyry sheet is shown in section, the summit of the hill being formed of limestone strata. The porphyry outcrop, followed southeast, diminishes very gradually in thickness for some distance, and then terminates so abruptly as to suggest a fault. No other evidence of a fault, however, can be found, and it is certain that no movement of great importance has occurred; moreover, no outcrop of porphyry representing the other side of a fault can be found. Northwestward the porphyry can be easily traced. It runs to the east of Lion Hill and is exposed high up on the northern wall of Ophir Canyon.

The Bird's-eye porphyry in the Mercur district, therefore, is only the edge of the main mass. It seems to have its greatest development considerably northwest of that of the Eagle Hill porphyry, although it appears at about the same horizon and on the same general topographical and stratigraphical line. It is probable, therefore, that they are

genetically connected,—that they represent the same general magma which ascended along the line of weakness induced by the mountain building, and crystallized at different times and under varying conditions.

No evidence of value with regard to the relative age of the two varieties of porphyry has been found. In a single place—on Lion Hill—a contact between the two was found, by the side of the road which leads to the mines, but it was of such a character and the rocks were so thoroughly decomposed that no evidence could be derived from it.

PRECIOUS METALS; GENERAL DISTRIBUTION.

A large part of the rocks in the Mercur Basin contain traces of gold, showing a very slight but widespread mineralization. Of two samples of hard, unaltered limestone from the Great Blue limestone, taken at places not in the immediate proximity of ore deposits, one showed a trace of gold, the other none. Two assays of the black shale in the upper belt contained no trace of gold or silver; one assay from the lower black shale belt showed a trace of gold. Nine assays[1] were made of altered limestone in places where the change seems to have been the effect of atmospheric agencies, and not to have been greatly influenced by any important mineralizing action. This altered rock was mostly of the pulverulent, bleached variety, such as is common in surface exposures. It seems probable, therefore, that any precious metals detected in it are only those which were present in the hard limestone, slightly concentrated, perhaps, by the weathering agents. Seven of the nine samples showed very small quantities of gold, the largest amount found being 0.025 ounce in a ton; the other two showed no trace. In none of them was any silver found. Four assays were made of comparatively fresh Eagle Hill porphyry. Two assays showed 0.01 ounce of gold per ton, one showed a trace of gold, and the fourth was entirely barren. Of two assays of the Bird's-eye porphyry, one showed 0.01 ounce of gold to the ton; the other showed a trace of gold. Three assays were made of the calcite veins, which are frequent in the limestone. These veins are of pure white, crystalline calcite, without admixture of other minerals; occasionally, however, they have been stained brown or yellow, probably by a slight admixture of iron. They do not appear to be in any immediate way connected with the chief mineralization. All three of these veins showed small quantities of gold, the largest amount being 0.025 ounce to the ton.

This shows that there is a slight mineralization which is pretty generally distributed throughout the rocks of the basin. On the other hand, in certain localities the mineralization has been so great as to furnish ores of gold and silver which have been profitably worked.

[1] Most of these assays were made for the Survey by Mr. R. H. Officer, of Salt Lake City, Utah, and in an especially careful manner. It is believed that the sources of error in ordinary assaying have been avoided, and that the results are accurate.

These localities, so far as yet shown, appear to be in all cases at the contact of the porphyry sheets with the inclosing limestone. This contact, however, is not always mineralized so much as to form ores—indeed, this condition is the exception. Twelve assays were made of specimens taken at the contact of porphyry and limestone, in places which contained no ore, and where there was no evidence of mineralization or other excessive metamorphism. In some of the samples the rock was quite hard, the limestone showing some silicification and the porphyry also being indurated; in others there had been a disintegration instead of a hardening, and both porphyry and lime were crumbling or reduced to a powder. The results of the assays can not be said to show more gold than is present in many of the other barren rocks of the district. Nine samples showed very small quantities of gold, the largest amount reported being 0.025 ounce to the ton, while three were entirely barren. All of them were examined for silver, but none was found in any case.

In certain localities, however, the contact becomes much richer and forms ore deposits. These deposits are found to be separable into two distinct groups, which are in nearly every characteristic strongly contrasted with each other and must be treated quite independently. In the first group the lime has become hardened at the contact of the porphyry and almost entirely silicified, so that it goes among the miners by the name of "black quartz;" and in this siliceous rock are found films and seams of chloride of silver, with sometimes argentiferous stibnite, sometimes thin films of the copper carbonates, and usually a large amount of barite. In the second group both lime and porphyry have been decomposed and are changed into a soft rock called "shale" by the miners. This is nearly black in the unoxidized condition, but yields very readily to surface influences, and becomes light-yellow, sometimes reddish and brownish. The first group contains only very small quantities of gold along with the silver, while the second contains practically no silver but enough gold to make the ores valuable. This ore is remarkable for the large quantity of arsenic which it contains, and also for the mercury sulphide which is peculiar to it.

The deposits belonging to these two principal groups are generally quite distinct one from another. To the siliceous outcrop characteristic of the first has been popularly given the name of the "Silver ledge," while the rock which contains the gold ores is called the "Gold ledge."

CHAPTER II.

THE SILVER LEDGE.

What is commonly known as the Silver ledge is a zone of highly silicified rock at the contact of the lowest of the three minor sheets of Eagle Hill porphyry which split off from the lower main sheet. The outcrop of this zone is prominent throughout a large part of the basin.

This zone or metamorphic border is sometimes very thick as compared with the size of the sheet of porphyry with which it is associated, while at other places it completely disappears; yet it is a pretty constant accompaniment of the lowest sheet of porphyry, and is never long absent from the contact. Its greater development in places is doubtless to be referred to local causes; but no law governing its general distribution can be found, other than that it characterizes the contact of porphyry and limestone. This phenomenon is confined to the Eagle Hill porphyry. Only the slightest trace of any such alteration was found in connection with the Bird's-eye porphyry.

DESCRIPTIVE GEOLOGY.

The Silver ledge is developed chiefly at the contact of the lower of the two principal sheets of Eagle Hill porphyry, and occurs only sparingly at higher horizons. On the northeast side of Sunrise Hill, overlooking Mercur Gulch, it appears in considerable thickness. The steep cliff into which it has been fashioned by erosion rises for a height of 60 feet or more, and is conspicuous from a distance. This outcrop is continuous for nearly half a mile, but disappears gradually on both sides, and the rest of the contact of porphyry and limestone on this hill does not show it.

MERCUR HILL.

Following the strike, one next finds the Silver ledge well developed on the side of Mercur Hill, just above the bed of Mercur Gulch. It is not so thick as before, averaging about 10 or 15 feet. This is a good place to observe the association of the Silver ledge with the porphyry and the dependence of the one on the other. The Silver ledge is much broken up and contains a good deal of barite. On the under side it changes gradually to hard, unaltered, blue limestone. The line of contact of the Silver ledge with the limestone is neither distinct nor regular, shifting up and down in a way which shows that it can not have been produced by sedimentation, but only by subsequent metamorphism. The rock of the Silver ledge is here much brecciated. The angular

or somewhat rounded fragments of cherty, completely silicified limestone are inclosed in a cement which is chiefly of white crystalline calcite, often with barite. Some of the fragments are also of altered porphyry.

The contact of the Silver ledge with the porphyry is quite distinct, and the greater erosion of the porphyry has marked the contact by a shelf 15 or 20 feet wide. The porphyry is considerably decomposed, contrary to its ordinary condition in the Silver ledge, where it has been early indurated, apparently at the same time as the silicification of the limestone, and therefore withstands later altering agents. It is, however, often quite firm. It is of a light-gray color, with no phenocrysts or crystalline structure visible to the naked eye except very small flakes of muscovite. In parts it is stained brown or yellow, and is often quite soft and crumbling. In the limestone below the Silver ledge there are numerous narrow, vertical calcite veins, running N. 18° E. In the broken and altered rock above, these do not appear, and there are no veins in the porphyry. This shows that, in this case at least, the formation of the fissures and cracks since filled with calcite was not later than the intrusion of the porphyry. The breccia of the Silver ledge was evidently formed at the time of this intrusion by the friction of the porphyry sheet against the limestone walls, and the filling up of the spaces between the fragments with crystalline calcite must have followed closely, being among the after phenomena of the contact metamorphism. It seems very likely, therefore, that the fissures in the limestone below may have been opened up at the time of the intrusion of the porphyry, and have been filled with calcite at the same time as were the breccias of the Silver ledge. The porphyry here is 15 to 20 feet thick, and above it the contact with the hard, blue, unaltered limestone is again well marked. A noticeable hardening and darkening of the limestone is found at this upper contact for a space of 3 to 4 feet, but it is very much weaker than that of the Silver ledge at the bottom. This locality offers valuable evidence as to the relation of the gold to the silver ores. The silver ores were worked somewhat by open quarrying at the time of the silver production of the camp.

The division of the lowest main sheet of Eagle Hill porphyry into several smaller sheets appears to take place in the little basin which widens out from the bed of Mercur Gulch, just south of Mercur Hill. In this basin lie the Mattie No. 5 and other claims. At the point where the Silver ledge has just been described these several sheets are developed. That one which is associated with the Silver ledge is the lowest and the thickest, although it probably averages not more than 15 or 20 feet. About 100 feet above this is a smaller sheet, which averages about 8 or 10 feet in thickness, but is very often less. This is usually greatly decomposed, and is associated in the closest manner with the ores of the Gold ledge. At about the same distance above the porphyry of the Gold ledge is a third sheet, the smallest of the

three, averaging probably 3 or 4 feet in thickness. This sheet does not appear to be greatly mineralized in any way. All three sheets are exposed on Mercur Hill, but the uppermost thins out and disappears in the bottom of the basin; at least, the continuation of it northwestward has not been traced. It is only the lowest which exhibits the Silver ledge alteration, although the Gold ledge porphyry shows decided traces of this action. The silicification and mineralization of the limestone at the contact with the lower sheet is nearly continuous all along the side of Mercur Hill, where openings have been made on it at various points.

MARION HILL.

In the bottom of the basin, near the town, the outcrop is hidden by the accumulation of drift material from the hillsides; on the north side, however, it appears at the base of Marion Hill, very near the Marion Mill, and follows up the southern side of the hill, rising with the dip. The alteration on Marion Hill and in the immediate vicinity has been especially intense. In many places it is difficult to identify the porphyry, and to distinguish it from altered limestone; and in several places the continuity of the porphyry seems to be interrupted, although the Silver ledge is nearly continuous, and the porphyry found at various points sustains the usual relation to the rock of the Silver ledge. Porphyry in a firm but decomposed state outcrops in the road just above the Marion Mill; and a little farther on, where it is softer, a tunnel is driven for a considerable distance in the prophyry. About halfway up the hill are the old Sparrowhawk mines, which were at one time actively worked. The workings are rather extensive, and the limestone is very much altered. It seems probable that parts represent a breccia of limestone with a porphyry cement, both greatly altered. No undoubted porphyry was seen in the workings, and it may well be that at this point and for some little distance up the hill the sheet became very thin, in places reduced to a mere breccia cement, without, however, interfering with the circulation of the waters which produced the alteration and mineralization of the limestone. A short distance southwest of the Sparrowhawk is an outcrop of softened, decomposed porphyry, into which a prospect tunnel has been run. For some distance from this point the outcrop is not strongly developed, but it forms a conspicuous feature at the head of Marion Gulch.

MARION GULCH AND WESTWARD.

In Marion Gulch is situated the old Carrie Steele mine, which was at one time one of the principal silver producers in the district. The Steele workings are directly under the present Marion mine, from which gold ore is being taken. At this point the Silver ledge has a remarkably broad outcrop, as if the sheet had here taken a local dip to the southward and the uppermost part had been eroded off, leaving bare the altered under-contact, whose angle of inclination corresponds

very nearly to the slope of the hill. Much of the rock is brecciated and is full of barite. On the west slope of the ridge, next west of Marion Gulch, the difference in altitude between the top and the bottom of the silicified zone is about 150 feet. The alteration, however, is irregular, and there are within this zone isolated patches of little-altered limestone. All along here the most-altered portion of the Silver ledge is essentially a breccia, in which the masses and fragments of limestone often exceed the amount of porphyry, and sometimes shut it out altogether, so that it has somewhat the character of an intermittent sheet. The upper part of the ledge seems generally to be an altered porphyry, altered and hardened at the contact. Above this is the porphyry, which did not feel the effects of the primary metamorphism, but which has been generally softened by later oxidation. It forms a narrow and irregular belt, and is often entirely wanting. Proceeding up the side of the hill, the Silver ledge is found to be continuously and strongly developed. Just before reaching the top of Fort Hill it is interrupted by an interval of unaltered limestone, which seems to mark a break in the continuity of the porphyry sheet. On the southwestern side of Fort Hill, however, it is again well shown, and forms a continuous outcrop. On it were situated the Queen of the West, the Mormon Chief, and various other silver mines, none of which, however, were very productive. In some of the open cuts the altered porphyry can be seen lying above the Silver ledge, in exposures varying from 1 foot to 5 feet in thickness. The altered limestone is very much stained, and is filled with veins of calcite, the most prominent of which are parallel to the contact and the bedding. This altered zone is here very thick, reaching 50 or 75 feet, although only the upper 20 feet or so is of the highly altered rock typical of the ore-bearing localities. From the Mormon Chief group the outcrop is nearly continuous along the side of Monument Gulch, crossing its bed and continuing, with a few breaks, nearly to the summit of the hill at a point overlooking Rush Valley. There are on the northeast side of Monument Gulch several exploration pits in the Silver ledge. A sample taken from one of these pits, very near where the ledge crosses the gulch, assayed 5.61 ounces in silver and 0.005 ounce of gold. Farther up the hill, on the upper contact of the intrusive sheet (the locality just mentioned is on the lower contact), the Silver ledge is somewhat developed, although by no means so well as at the lower contact. The zone of alteration is narrow and the change plainly not so profound. A sample was selected here from a pit almost directly above the locality from which the sample just mentioned was taken, which assayed in silver 0.16 ounce to the ton, with a trace of gold.

SILVER CLOUD SHAFT AND VICINITY.

Where the lower porphyry sheet is exposed on the hills to the north of the Silver Cloud shaft and tunnel the limestone is silicified at several places along the contact, and the slightly irregular relation of the sheet to the stratification here, together with the unequal erosion, has oper-

ated so that several silicified bands form parallel ridges, as seen on the map. This structure is usually supposed by the miners to be due to faulting, but the unchanged position of the associated limestones shows that this hypothesis is not correct. The altered rock is well exposed in Silver Cloud Gulch, but the maximum alteration seems to have taken place in the neighborhood of Silver Cloud shaft.

The Silver Cloud shaft is situated in the bed of Silver Cloud Gulch, just above the point where the gulch opens out into the broad flat in which lie the mouth of Silver Cloud tunnel and the Silver Cloud spring. Here the Silver ledge outcrops as a broken, cherty zone containing an abundance of irregular veining, in which barite is especially plentiful. The shaft is about 55 feet deep, and at the bottom a drift runs about N. 50° E. for nearly 200 feet. The whole 55 feet through which the shaft passes is of the Silver ledge material. Most of it is easily recognized as an altered limestone, for the stratification can be readily seen. In places it appears like a somewhat altered and mineralized quartzite.

The drift at the bottom of the shaft follows a strongly fractured zone, which has a trend of N. 50° E. and a general dip of 70° NW. The actual strike of the rocks is about N. 60° E. and the dip is about 27° SE. The fractures are open, without vein filling. They often show slickensided walls, indicating slight faulting. At the end of the main drift the fissures are especially large, which is probably due in large part to the crumbling and partial erosion of some of the sheeted rock adjoining the chief fracture zone. The largest is wide enough at this place to admit a man's body, and several are wide enough to admit an arm. These fractures are like those in the Silver ledge at the Carrie Steele workings, where a large open fissure, wide enough to receive the body of a man, was encountered, and was explored for ore for a considerable distance, without widening. It was found, however, that the fissure had no connection with the location of the ore; and it will be shown later that all these northeast open fissures are probably later in origin than the ores of the Silver ledge. The rock which the fracture planes cut in the Silver Cloud is extremely metamorphosed. It is an altered, cherty, and broken limestone, generally dotted with small blotches of calcite or barite, giving it a porphyritic appearance under ground. Veins of crystalline calcite cut it in every direction and at the end of the main drift form a perfect network. There are often geodes, some of them as much as 2 or 3 feet in their longest diameter, which are lined with magnificent crystals of dog-tooth spar, making by candlelight a very beautiful sight. Barite is quite common, in small bunches scattered through the rock or in larger pockets, veins, or geodes, where it forms tabular crystals, often an inch long, which are generally frosted with calcite. Very thin films of malachite, azurite, and red oxide of copper are frequently found. There is a cross drift about 75 feet from the main shaft which extends about 100 feet to the southeast of the main drift. Like the main drift,

this runs through broken and cherty limestone, with several strong fracture planes. For 25 feet from the end of the drift the roof runs along under the grass roots. About 15 feet from the end there is a coarse fault-breccia, very soft and unaltered, which corresponds in trend and hade with the other fractures. Near the end of the main drift another cross drift runs southeast for 30 feet in broken and cherty limestone. There may here be distinguished a set of minor fractures running at right angles to the main set. In the crevices there is a good deal of the soft white mineral known in Leadville by the name of Chinese talc, with some stibnite and thin coatings of hematite.

It is evident that the open fissures were later in formation than the calcite veins and geodes. The walls of the fissures are sometimes bare, but there is generally a thin coating of calcite; they cut abruptly through the large calcite veins and geodes. In some places, too, there appears to have been a very slight faulting, which emphasizes the same point, the vein or geode being raised or lowered a little on one side relatively to the other.

The contact of porphyry and limestone is shown at several places between Silver Cloud Gulch and Porphyry Gulch in open cuts or shallow shafts. There is here a trench showing the contact very clearly. The porphyry, as exposed, cuts the silicified limestone rather irregularly, but still follows the bedding approximately. It is sheeted parallel to the bedding of the limestone. In places it is much decomposed, and being fine-grained and without noticeable phenocrysts, resembles a sedimentary rock, from which, however, it is readily distinguished by the contact phenomena as well as by its total difference in appearance from the rock of the Silver ledge, which is really an altered sedimentary. The contact is very well defined, which may be attributed to the fact that the indurating and silicifying action has not been intense, as compared with that of the Silver ledge on Marion Hill and immediately west. Near Porphyry Gulch, where the outcrop of the porphyry sheet turns a rather abrupt angle, is a shallow pit, 15 or 20 feet deep. The western side of the pit is on the contact of limestone and porphyry, which at this point is nearly vertical; the eastern side is in a talus deposit. The hardened contact has at one time formed a cliff at this point, at the foot of which talus accumulated and grew until level with the top. At the contact there are plentiful breccias developed, and very good specimens of stibnite in radiating clusters are found. An interesting fact shows that the stibnite was deposited later than the formation of the breccias. In several cases a continuous film of stibnite follows a crevice which passes from a fragment in the breccia to the apparently igneous matrix.

Northwestward along the outcrop of the porphyry, the Silver ledge shows at intervals. It is especially well developed on the northwest side of Silverado Canyon, where much exploration for ore has been made, and where the abundance of the altered limestone and the dis-

FACE OF DRIFT IN SILVER CLOUD MINE.

Showing open fissures in Silver ledge.

tance from the porphyry to which the alteration often extends remind one of the similar outcrop running west from Marion Hill.

Following the same sheet southeast, beyond the area of the Mercur Basin map, the Silver ledge is exposed in various places, while between these outcrops, on the same contact, the softer and decomposed rock is actively prospected for gold. Where the lower belt crosses Sunset Gulch there is a good outcrop of silicified limestone and porphyry, with a sharp contact. The porphyry is light-gray or brownish and very firm, with wavy secondary banding, due to incipient decomposition. An average sample of this rock was assayed and showed 0.70 ounce of silver to the ton and 0.015 ounce of gold. From this point the silicified zone may be easily followed, although outcropping only at intervals, past Glencoe down the road nearly to Sunshine. At no point south of the Mercur Basin, however, has there been found sufficient mineralization to make mining profitable, although it has been attempted at the Glencoe mine.

Along the contact of the upper sheet of porphyry there is very little mineralization or other metamorphic phenomena. On the trail between Mercur and Sunshine, at the top of the divide, there is a slight silicification extending for a short distance, but the alteration, although of the same class as that in the lower sheet, has been neither widespread nor profound, and although it has been prospected it appears to carry only very small quantities of silver.

NATURE OF ORES.

QUARTZ.

It may be said, in recapitulation, that the characteristic and ever-present mineral which accompanies the ore is the cherty impure quartz. Among the miners this goes by the name of "black quartz," and is often considered, although without a great deal of reason, to be a favorable sign, not only in the Silver ledge, but also in the gold ores, where it is more sparingly present. Very few ledges of this dark chert can be found which do not contain some silver, but in most of them there is no considerable quantity. Complete silicification was evidently one of the primary stages of the metamorphism, and did not necessitate such violent action as did the introduction of the ores. This is exactly what should be expected, when we consider the abundance of silica as compared with the quantity of the metals in the natural solutions which we have the opportunity to examine. It is somewhat peculiar, however, that the quartz which was introduced so abundantly at this time is almost entirely in this impure, megascopically amorphous condition and that very little of it found an opportunity to crystallize. This fact is significant of the conditions of mineralization. Quartz in crystals large enough to be recognized without the use of the microscope is rare, in both the gold and the silver ores. It occurs in cavities of small size and irregular form, which have evidently been produced by dissolution, and which are entirely inclosed by the surrounding rock. On the walls of these cavities it forms frosty coatings, of which

the individual crystals can be well made out only with the aid of a magnifying lens. Along small, irregular, minor cracks it has also often separated out, and it forms coatings of the same nature on the barite, when the latter is crystallized in such a manner as to leave spaces between the individuals.

CALCITE.

Next in order of abundance among the characteristic minerals of the Silver ledge comes calcite. The silicifying solutions which replaced the limestone with silica deposited very little quartz in the numerous vein-like cavities which were developed at the time of the same metamorphic action. The lime, on the other hand, after being entirely expelled from the rock, came in and crystallized plentifully as pure, white calcite in the numerous fissures and cavities which were opened by the silicifying solutions, forming veins, often several inches wide, and lining the walls of large cavities with beautiful crystals of dog-tooth spar. These veins are found nearly everywhere. Sometimes they become so abundant as to form no inconsiderable part of the bulk of the rock; and yet they are somewhat more indicative of considerable mineralization than is the silicified limestone alone. This does not necessarily show, however, any close connection in deposition between the calcite and the ores. More probably it is really the honeycombed condition of the rock which is significant of the intensity of the action accompanying or inducing mineralization, and the calcite, coming later, filled by a much slower process the cracks and irregular cavities formed by the corrosive action of the mineralizing solutions. The calcite veins are not intimately associated with the ore. They are usually quite barren, which is another fact pointing to the same conclusion.

BARITE.

Next in order of abundance comes barite, which is more restricted in its distribution than the other minerals previously described, and also more closely associated with the occurrence of the ores. It is somewhat different in habit from either the calcite or the quartz. It occupies irregular spaces in the rock, scarcely ever forming veins with well-defined walls and constant width and direction. Often portions of the cherty rock of the Silver ledge are included in it, so that there is a resemblance to a breccia; but frequently there is at the contact of barite with chert a zone of transition from one to the other, which suggests that the barite may have replaced the limestone at the time of silicification, and that barite and silica were contemporaneous in introduction. Some of these irregular masses of impure barite are several feet in diameter, and such a body may be seen outcropping on the road leading up the hill from the Marion Mill; but there is much that is disseminated in the rock in small blotches, without conspicuous crystallization. Tabular crystals of barite are often found lining the walls of small cavities, which in most cases they nearly fill. These crystals are irregularly aggregated, leaving spaces between the individuals,

and are grayish-white in color. They are usually frosted with very small and perfect crystals of quartz or calcite, which often entirely conceal the barite.

Although the best ore of the Silver ledge does not always accompany the barite, yet in a general way this mineral is a sure index of considerable mineralization. It is especially plentiful in those portions of the ledge from which ore has actually been extracted, such as the Silver Cloud, the Sparrowhawk, the Carrie Steele, and other claims; while in the poorer portions of the ledge it is much less frequent. It has actually been observed, in places, that the barite is the gangue in which are embedded the small portions of the metallic sulphides that doubtless furnish the ore. But although it is the gangue of the ore, it appears that the barite itself does not necessarily contain silver in any large quantity. An assay was made of a specimen from the Silver ledge in Gold Dust Gulch, not far above the Geyser Mill, which was estimated to contain 50 per cent of barite. In some of the specimens from this same place small particles of stibnite were found inclosed in the barite. The assay showed only 0.54 ounce of silver to the ton, with no trace of gold.

STIBNITE.

Antimony is a constant and characteristic accompaniment of the Silver ledge ores, and in its recognized form occurs as stibnite. It is never in large quantities, forming at the best sparingly disseminated bunches of thin, radiating crystals, which rarely exceed an inch in length. It also occurs as small bunches of irregular shape, each bunch being only a small fraction of an inch in diameter, and very commonly in thin films filling crevices in the rock.

Stibnite is associated with silver in the very closest way. It is probable, indeed, that in their primary state the two metals crystallized together. Mr. R. C. Hills, in his paper on this district,[1] states that in one claim "the silver-bearing material is an argentiferous sulphide of antimony." A specimen of the antimony sulphide taken from the contact of porphyry and limestone, at a point near Porphyry Gulch, east of the Silver Cloud shaft, was examined for silver. Only a very small quantity of the mineral was available for analysis, and the results were not conclusive. A faint mirror was obtained, which was probably silver, but which was so small as to leave its presence doubtful. The analysis of silver ore from the Sparrowhawk mine shows a considerable amount of antimony, although no antimony mineral was noticed as megascopically present in the ore. (See p. 394.)

COPPER.

Thin films of copper, chiefly the carbonates malachite and azurite, are found in several places in the Silver ledge, and, like antimony, seem to be very closely associated with the silver. These very small quanti-

[1] Proceedings of the Colorado Scientific Society, August 6, 1894: Ore deposits of Camp Floyd mining district, Tooele County, Utah.

ties of copper show at the same time the connection and yet the difference between the ores of the Mercur district and those of the Ophir district, to the north, and the Tintic district, farther away to the south. In both these districts copper forms a conspicuous part of the ores; in Tintic it has been an important article of production. These copper stains are abundant in the rock at the Silver Cloud shaft. A specimen was selected for assay, consisting of many fragments from various parts of the workings, each bearing a film of copper carbonate. The results showed 25.9 ounces of silver to the ton, and 0.04 ounce of gold, the largest of fourteen assays of various portions of the Silver ledge.

ARSENIC.

The analysis of the Sparrowhawk ore shows a small quantity of arseniates. The arsenic is never, so far as observed, recognizable megascopically in the rocks of the Silver ledge; and in only one section has it been noticed microscopically. In this case a chert which carried megascopically large flakes of stibnite showed under the microscope numerous small grains of scorodite. It may be that some of this arsenic is an original constituent of the ores of the Silver ledge; but where these ores are overlain by the gold ores it is probable that much of the arsenic has leached down from the latter. One of the characteristic features of the Gold ledge in its unaltered form is arsenic in the form of the sulphide, realgar. The ore oxidizes very readily to a considerable distance below the surface; the realgar is converted chiefly into arseniates, among which the arseniate of iron, scorodite, is most abundant. These arseniates are very soluble in the ordinary atmospheric waters, and show evidence of being leached out of the gold ore. It is only natural that some of these solutions should sink to the Silver ledge below and there leave a portion of their burden, taking up new elements with slightly changing conditions. No sulphide of arsenic or other arsenic mineral in recognizable quantities has been found in the Silver ledge.

CHINESE TALC.

A soft, white, clayey mineral, which appears to be identical with the Chinese talc of Leadville, is found quite abundantly filling crevices vein-wise in certain parts of the Silver ledge. A great deal of this was found in a part of the Silver Cloud workings. It is thus described at Leadville by S. F. Emmons:[1]

The miners' term, Chinese talc, has been retained for a substance which is found with singular persistence along the main ore channel or at the dividing plane between White Porphyry and underlying limestone or vein material, and also at times within the body of the deposit. It is composed of silicate and a varying amount of sulphate of alumina, to which no definite composition can be assigned. It is compact, semi-translucent, generally white, and so soft as to be easily cut with the finger nail. It is very hygroscopic; hardens and becomes opaque on exposure to the air.

[1] Geology and Mining Industry of Leadville, Mon. U. S. Geol. Survey, Vol. XII, Washington, 1886, p. 377.

On page 603 of the same work this mineral is classified among the alteration products of porphyry, and five complete analyses are given. The Mercur mineral has not been analyzed, but it is in all outward characteristics the same as that in Leadville, and, like it, seems to be an alteration product of the porphyry. It is believed not to have been formed at the same time as the barite, stibnite, and silver, but to have had a later and slower formation, keeping pace with the decomposition of the porphyry.

PYRITE.

Pyrite is not recognizable megascopically in the ores of the Silver ledge, and the analysis of the Sparrowhawk ore shows that it is absent. In a single thin section from the Silver ledge in Silver Cloud Gulch, some distance above Silver Cloud shaft, pyrite in small, irregular grains and seams was noted.

GOLD IN THE SILVER LEDGE.

It appears from nearly every assay of the silver ores that they constantly contain very small quantities of gold. Of fourteen assays made of ores from various parts of the Silver ledge, all but one were found to contain some gold. Four of the thirteen gold-bearing specimens showed only traces; the rest contained weighable quantities, although the greatest amount in any one was only 0.04 ounce to the ton. Several other samples contained very nearly as much. From this constant occurrence it follows that, contrary to the common belief at Mercur, gold in small quantities is a very constant accompaniment of the silver ores. It is also evident that this gold is very closely associated with the silver, if indeed it was not deposited at the same time. To account for the occurrence of gold in the silver ores of Marion Hill it has been assumed that the metal had leached down from the gold deposits above, and thus was an impurity of very recent origin. This hypothesis is very plausible when the locality is in the immediate vicinity of the gold ores, but in point of fact the sample which showed the largest amount of gold in the silver ores was taken from the Silver Cloud shaft, at a considerable distance from any known gold mineralization. There are certain places on this horizon where a larger amount of gold has been found, but here the characters of the rock, as well as the contents, indicate a transition between the silver and the gold deposits. They will therefore be described when the relationship of the two is considered.

SILVER.

The silver ores of the Mercur district differ distinctly from the ordinary varieties in being accompanied by very little metallic gangue. Especially are they different from the ordinary silver-lead ores of this and other regions in that they do not contain a trace of lead. The ore consists of very small films of chloride of silver disseminated through the altered and silicified limestone, and in most places it does

not appear to be closely associated with any other mineral. It is therefore difficult to judge the value of the ore by inspection, on account of the absence of accompanying baser ores; for there may be enough silver chloride scattered through the rock to make the ore valuable, and yet it could hardly be detected.

Fabulous stories are told of the richness of small pockets of ore which were taken out of the Sparrowhawk and the Carrie Steele in the old days. But opposed to these is the fact that the mines were never for any considerable space of time remunerative, even when silver was at double the present price. To offset the small bunches of rich ore, there are large quantities of rock very poor in the metal. Of the assays made in the course of the survey of the district, the largest return was of a picked sample from the Silver Cloud shaft, which assayed 25.9 ounces to the ton. A general sample from the Mormon Chief mine, on Fort Hill, yielded 19.15 ounces of silver; another general sample from the same place gave only 0.21 ounce. This shows the great variation. The lowest amount of silver found in the typical completely silicified rock was 0.16 ounce to the ton. The mineralization may be characterized, therefore, as very variable in any one place, but remarkably uniform considering the vast amount of the silicified rock which outcrops along the contact and which everywhere shows ponderable quantities of silver.

ANALYSIS OF SILVER LEDGE ORE.

Following is the result of a complete analysis of a sample of the Silver ledge rock, taken from various points in the Sparrowhawk workings on Marion Hill. The analysis is by Dr. W. F. Hillebrand, of the Survey:

Analysis of the Sparrowhawk ore.

	Per cent.
Silicon dioxide (SiO_2)	81.70
Titanium dioxide (TiO_2)	.20
Aluminum sesquioxide (Al_2O_3)	3.24
Iron sesquioxide (Fe_2O_3)	5.41
Iron protoxide (FeO)	.28
Iron disulphide (FeS_2)	None.
Manganese protoxide (MnO)	None.
Calcium oxide (CaO)	.44
Strontium oxide (SrO)	None.
Barium oxide (BaO)	.43
Magnesium oxide (MgO)	.16
Potassium oxide (K_2O)	1.10
Sodium oxide (Na_2O)	.12
Lithium oxide (LiO)	Strong trace.
Water below 110° C	.29
Water above 110° C	2.16
Sulphur trioxide (SO_3)	2.97
Phosphorus pentoxide (P_2O_5)	.05
Antimony pentoxide (Sb_2O_5)	1.02
Arsenic pentoxide (As_2O_5)	.40
Arsenic disulphide (As_2S_2)	None.
Molybdenum (Mo)	Strong trace.
Tellurium (Te)	Strong trace.
Total	99.97

GENESIS OF THE SILVER ORES.

It may be said, in recapitulation, that the original form of the silver in the Mercur district seems to have been a sulphide, which crystallized simultaneously with sulphide of antimony and small quantities of copper. It is probable that the copper was also originally in the form of sulphide, although not now found as such. These metals are sparingly distributed in a gangue of barite and of very abundant quartz.

LOCUS OF MINERALIZATION.

The mineralization has taken place at the contact between the porphyry and the limestone, especially the lower contact. Typically the point of greatest mineralization is in the limestone directly on this contact, and from this point it extends into the limestone away from the porphyry, the amount of mineralization decreasing with the increasing distance. The effects of the metamorphism totally disappear at a little distance from the contact, and the limestone below is of an entirely unaltered character. The thickness of the zone of alteration is generally not more than 10 feet; in the most highly mineralized places it becomes 20 to 50 feet, and 100 feet may be safely considered its maximum. So far as observed, nowhere does the mineralized zone deviate in any noteworthy way from this line of contact; nowhere does it extend for any considerable space into the porphyry, and nowhere does it follow any steeply dipping zone, such as would be caused by planes of fracture or by any other structure. Moreover, in the zone which is actually mineralized there are no fractures or other obvious water channels through which the mineralizing agents could have come, except the complicated and nonpersistent minor fractures which are so plentiful in the limestone at the contact with the porphyry. These minor fractures, which become so profuse as to produce breccias, are well developed only at the contact, and they diminish rapidly with increasing distance. Their chief direction is seen in many cases to correspond to the local trend of the contact, and every indication shows that they were formed at the time of the intrusion of the porphyry by the friction of this rock on the rigid sedimentaries.

NATURE OF MINERALIZING AGENTS.

The assembled phenomena indicate that the mineralizing agents were heated waters, which circulated along the contact for a comparatively brief period, during which, however, they appear to have been very active. These waters contained silica, with a good deal of barium, and small quantities of antimony, copper, and silver. The commonest work of these solutions—the removal of the lime and the deposition of the silica by a process of gradual replacement, without destroying many of the original features of the rock—is a phenomenon which has been many times noted as the result of circulating waters, especially of heated

waters. The various stages of the alteration here in Mercur have been observed under the microscope. In Leadville the same alteration phenomena are abundantly shown, for there the limestones in the immediate vicinity of the ore deposits are largely altered to chert, and the derivation of one from the other is very clear. Mr. Frank Rutley[1] has described several cases of cherts owing their origin to the gradual replacement of limestone by silica from ordinary surface waters, and is of the opinion that the fine-grained siliceous rocks of Arkansas, known as novaculites, are of this origin. The silicification of sedimentary rocks in the neighborhood of eruptive masses has often been observed as one of the most conspicuous among contact phenomena. Daubrée[2] points out that in the vicinity of eruptive rocks quartz has often accumulated in compact crystalline masses or in a jasperoid condition; and the same observation has been made by other geologists. G. W. Hawes shows that at the contact of the Albany granite with the schists, the latter rocks have become dehydrated and silicified.[3] Changes of a similar nature have been observed in the Hartz, where limestones have been silicified near granite, forming a broad alteration zone following the contact.[4] Geikie speaks of the induration of rocks as one of the most common phenomena of contact metamorphism, and one which results, generally, from the deposition of silica from heated waters.[5] "The most obvious examples of this action," he says, "are those wherein the percentage of silica has been increased by the deposit of a siliceous cement in the interstices of the stone, or by the replacement of some of the mineral substances by silica." It is evident, then, that the silicification of the limestone of the Mercur district at the contact with porphyry is nothing new, but is one of the frequently observed effects of contact metamorphism.

As Daubrée has shown, it is to the action of waters accompanying the eruption of rocks that most of the effects of contact metamorphism are due, and not to the effects of heat alone. Dry heat, indeed, plays an inconspicuous part. Eruptive rocks in the molten condition contain a notable quantity of water which has apparently been derived from the same deep-seated source, and has had the same history from the time of the upward movement of the lava, as have the other constituents. The study of volcanic action makes it appear probable that a large part of this may formerly have been atmospheric water, which has reached the deeper regions by gravity, capillarity, or confinement within sedimentary beds and subsequent deep burial beneath other strata. Having attained the deeper region, this water, under the influence of the high temperature, would become possessed of tremendous expansive force, which must finally find relief in the direction

[1] On the origin of certain novaculites and quartzites; Quar. Jour. Geol. Soc., Aug., 1894.
[2] Géologie expérimentale, Paris, 1879, p. 136.
[3] Am. Jour. Sci. (3), 1881, Vol. XXI, p. 28.
[4] Lossen, Zeitschr. Deut. geol. Gesell., Vol. XXIV, 1872, p. 777.
[5] Text-book of Geology, 1885, p. 558.

of least resistance—that is, in the direction of the surface. It would then ascend by the easiest channels, carrying with it the molten material with which it had become intimately mingled during its sojourn in the depths. But, for the purposes of economic geology, it is perhaps not profitable to go back so far. We may content ourselves with the generally admitted fact that water forms an essential part of lavas, from the moment when the ascent from the subterranean reservoir begins; previous to this it may have been derived from surface sources, or may be a product of chemical reactions in the unknown workshop of the earth's interior. The water which the lavas contain is not emitted till the actual moment of solidification, when by the process of crystallization it is separated out and becomes conspicuous among the now solid components by reason of its persistent fluidity. When the solidification takes place at the surface it forms the clouds of steam which issue from cooling lavas; but where the rock is intrusive, so that the water which is separated is still under sufficient pressure to keep it in the liquid state, there must result intensely heated solutions, capable of a great degree of corrosion. These solutions must act most violently at the contact; they become rapidly cooled on penetrating the adjoining rock, and in the case of small bodies of igneous rock they probably become at a short distance incapable of any great altering power. "The singular property that the molten silicates of lavas possess," says Daubrée,[1] "of retaining for a very long time, and up to the moment of their solidification, considerable quantities of water, clearly demonstrates that the action of heat does not exclude that of water, and seems to show that the latter has, even at high temperatures, a certain affinity for the silicates."

The width of the zone of alteration thus following the contact of an igneous with a sedimentary rock varies constantly with the nature and size of the intruding mass, the nature of the sedimentary rock, and other conditions. Along the same contact, moreover, between the same eruptive and the same sedimentary rock, there are great differences. But it has been remarked that at points where the eruptive rock forms reentrant angles the zone of alteration is greater than at projecting angles.[2]

In the alteration of the limestone near the porphyry in the Mercur district are found very nearly the typical phenomena of such contact metamorphism. There is the unvarying silicification of the limestone, and the approximate continuity of the alteration zone with the contact, together with considerable differences in intensity and amount of alteration at different points. Somewhat the same relation as is noted by Daubrée between the width of the altered zone and the reentrant angles formed by the igneous rock at the contact has been observed at Mercur. As will be seen by inspection of the map (Pl. XXVI), the

[1] Géologie expérimentale, Paris, 1879, p. 152.
[2] Op. cit., p. 134.

greatly altered limestone in the vicinity of the Silver Cloud shaft is situated in such a reentrant angle, and doubtless this is the cause of its great metamorphism, for in such a position the limestone is exposed to the porphyry on two sides, and therefore to a proportionately augmented amount of the metamorphosing solutions.

DURATION OF ACTION OF SOLUTIONS.

Apart from theoretical considerations, the actual phenomena of the Silver ledge indicate brief and intense action. That the waters must have been highly heated and capable of great metamorphosing influence, is shown by the complete replacement of the limestone by silica, and by the great corrosion which the rock has undergone. The whole mass is full of irregular cavities of dissolution, especially where the alteration has been greatest; some of these are of considerable size, occasionally several feet in diameter, while the others are small. Where the change has not been so great, there is still a complete silicification of the limestone, but the dissolution spaces are not so numerous. This may, perhaps, indicate that the formation of the cavities was in general slightly posterior to the silicification, and therefore that the process included the dissolving out of silica. But whether the material which was removed from these spaces was lime or silica, such a riddling of the rocks as is occasionally seen must indicate very active agents of solution. On the other hand, it is shown by the fact that the effects of this change do not reach far from the contact that the action could have gone on for a comparatively brief period only, and therefore that the supply of metamorphosing solutions was soon exhausted.

SOURCE OF BARITE AND OTHER CHARACTERISTIC MINERALS.

The barium, which is found in the Silver ledge in the form of heavy spar, was also probably derived from the cooling eruptive mass. This element is of frequent occurrence in igneous rocks, although rare in sedimentaries. It is often found in the feldspars, and forms an essential constituent in one variety—hyalophane. At Leadville chemical analysis showed barium to be commonly present in the porphyries, while none was found in the sedimentaries.[1] For the metallic constituents, relatively small in amount, the same source may be looked to. The researches of Sandberger and of American geologists have shown that most of the metals found in veins are present in the eruptive rocks, probably as original constituents, especially in the dark-colored silicates, such as biotite, hornblende, and olivine.[2] These metals, therefore, were probably present in the magma. On crystallization a portion of them would be taken up by the forming minerals,

[1] Geology and Mining Industry of Leadville, Mon. U. S. Geol. Survey, Vol. XII, 1886, p. 592.
[2] F. Sandberger, Untersuchungen über Erzgänge, 1882.

and the small amount left, dissolved in the heated waters expelled at the same time, would be carried out and deposited in the inclosing rock, wherever conditions were favorable.

GENERAL ASCENDING MOTION OF SOLUTIONS.

Inspection of the map and consideration of what has already been said will disclose the following significant facts concerning the distribution of the Silver ledge mineralization with reference to the different sheets of Eagle Hill porphyry at various horizons. The upper and larger sheet, if contact metamorphism were dependent on the heat exerted by the molten rock, should show the greatest effects of alteration; actually, however, it shows the least. In only one place on the map is a Silver ledge mineralization of the upper sheet indicated, and in this place it appears from its effects to have been neither intense nor prolonged. The phenomena include little besides the complete silicification which has been mentioned as the most elementary stage of the alteration, and the zone which has undergone this change is only a few feet thick. Nowhere on this contact has the mineralization been sufficient to tempt the working of the rock as ore. It is on the lower of the two chief sheets that the strongly marked mineralization is found. Again, when this lower sheet is undivided the mineralization is characteristically greater on the lower contact than on the upper. When it splits into several thin sheets, as it does in crossing the actually productive mining region, the Silver ledge mineralization is confined chiefly to the lowest of these sheets. On the middle sheet, with which the gold ores are associated, there is evidence of some small amount of mineralizing action, identical and probably contemporaneous with that of the sheet below. This will be mentioned later, in the consideration of the gold ores and their relation to those of silver. The amount of alteration, however, is not at all comparable to that of the typical Silver ledge. Finally, along this lowest thin sheet, the alteration is chiefly on the lower contact, though also developed on the upper contact, and sometimes strongly. These facts may be summed up in the concise statement that the Silver ledge contact-metamorphism follows the contact of the Eagle Hill porphyry with the inclosing rocks, and no other line, and that the metamorphism becomes progressively more profound with the lower horizons.

It is not implied by the application of the theory of contact metamorphism to the explanation of these alterations that the solutions which have altered the rock at any one locality have been derived solely from that portion of the eruptive rock which is immediately adjacent. Considering the probable processes, this is evidently unnatural. The solutions, exuding at every point from the cooling rock, must have found in the limestone immediately adjacent a zone where the passage of solutions was made relatively easy by the opening of fissures and the formation of

breccias, this zone being due to the strain exerted on the rigid inclosing rocks by the moving lava at the time of its intrusion. These waters, being, as has already been stated, intensely heated and under great pressure, would tend to move along this broken zone, and, wherever possible, in an upward direction. The porphyry in the Mercur district is in the form of sheets, but somewhere in the vicinity there must be some more direct connection with lower regions; and in the district actually mapped it is found that the sheets often cut across the stratification. At such places as these the waters would rise rapidly, and would traverse a much greater distance from their point of emergence from the cooling lavas than where the broken zone was horizontal. At points where the circulation was retarded, owing to the more nearly horizontal position of the channels, or more probably to the slighter development of the broken zone, the waters would accumulate and the mineralization would be greatest. It is along the minor bodies of porphyry that the mechanical disturbance occasioned by the intrusion must have been least, and here, therefore, the solutions accumulating from the freer passageways at the contact of the larger bodies would produce the greatest mineralization.

This explanation applies satisfactorily to the phenomena described. To the general ascensional tendency of the waters which followed the contact may be attributed the increasing mineralization with greater depths. The lower contact of the lowest sheet would receive not only the waters derived from its immediate locality, but also a possible supply ascending along some feeder lower down, and these solutions would exert a constantly diminishing influence on the successively higher contacts. Moreover, the greatest mineralization does not necessarily attend the largest sheets of porphyry; on the contrary, the most metamorphism, as mapped in the Mercur Basin, is at the contact with the smallest sheets. The chief alteration is that which follows the contact of the lowest thin sheet, after the main lower sheet splits into several. Here the thickness of the porphyry probably does not average more than 20 feet, while the main body, as exposed just south of Sunrise Hill, is several hundred feet thick; but at the contact of this thick sheet the alteration is comparatively small. The application to this case of the theory already stated would be that the solutions proceeding from the larger mass of the main sheet were retarded in their progress by the more difficult passage which the more slightly fractured zone along the smaller sheet offered, and so here produced the most marked effects.

While the theory which has here been adopted for the origin of the mineralizing waters appears the most satisfactory, it is not meant to disregard the possibility that they may have been derived from other and commoner sources. Surface waters, sinking into the earth, come in contact with bodies of heated rock, and then rise to the surface again, emerging as hot springs. The extreme importance of this hot-spring

action in the formation of ore deposits is generally recognized, and some particular phase of this action may possibly account for the silver ores of Mercur.

EFFECTS OF CONTACT METAMORPHISM ON THE PORPHYRY.

It is a fact which has an important bearing on the theory of the mineralization of the Gold ledge, as subsequently stated, that where the alteration has been greatest along the Silver ledge contact, not only the limestone, but to a less degree the porphyry, has been changed and indurated. This action is especially conspicuous where the alteration of the limestone has been greatest, as on Mercur and Marion hills; also on the boldly outcropping ledge which runs west along the edge of the Fort Hill ridge, and in the vicinity of Silver Cloud shaft. In places like these the actual contact is generally quite obliterated, and the two rocks are confounded so that it is often difficult to decide whether a certain specimen was originally porphyry or limestone. Below this anomalous zone the rock is of the cherty sort which is usual in the Silver ledge. Above, the light-brown color, the lack of any trace of stratification, and the irregular manner in which the rock is distributed show that it was originally porphyry; but it is always hard and siliceous, and has apparently been so indurated that it is not readily susceptible to later changes. Weathering agents have attacked that which was not altered at this time, and decomposed it so that it is reduced to a soft powder or clay, or has so little cohesion as to be easily broken with the fingers, but the indurated porphyry described above has been little affected. Where the lowest thin sheet of porphyry crosses the Mercur Basin, in the vicinity of Mercur and Marion hills, it has been thus indurated for the most of the distance. At intervals portions of the rock are found which have escaped this action and thus prove the original nature of the whole. This phenomenon is believed to have a considerable bearing on the question of the nature and origin of the gold ores, as will be described later.

SUMMARY OF SILVER LEDGE GEOLOGY.

The presence of silver ores is one of many phenomena characterizing a zone of altered limestone which follows somewhat irregularly the contact of Eagle Hill porphyry, especially that of the lowest sheet, and more especially that of the lower surface of the lowest sheet. This zone is marked by the complete silicification of the limestone and by the presence of barite in irregular masses, with small amounts of stibnite and a little copper and silver. The copper is in the form of a carbonate; the silver occurs as chloride, and probably also as sulphide, associated with sulphide of antimony. There is also evidence of a considerable degree of straining and fracture at the time of the introduction of the eruptive rock; breccias are very common and are often on a large scale; many fissures cross the altered rock, but do not persist far into the

mass of unaltered limestone, and there are irregular cavities which have evidently been formed by the corrosive action of circulating solutions. The walls of these cavities and of many of the fissures are often thickly covered with calcite, whose large and perfect crystals indicate a slow and quiet period of formation, and which was evidently deposited soon after the main alteration.

It is probable that all of the silver and copper, together with the antimony, was originally deposited as sulphides. The nature of the phenomena of the altered rock, briefly recapitulated above, shows that the mineralizing agents were waters. These mineralizing waters contained in solution chiefly silica, with considerable barium and small amounts of antimony, silver, and copper, which were deposited in the usual form for deposits not immediately connected with the surface—the silica as quartz, the barium as sulphate, and the metals as sulphides.

The completeness of the change in the Silver ledge and the evidence of active corrosion exhibited by the spaces of dissolution show that the action must have been temporarily intense, while the relatively narrow zone occupied by the altered rock and its failure to extend far from the most severely broken zone indicate that the action could not have been prolonged. The absence of large bodies of the metals, which, being relatively rare in solutions, require a considerable duration of chemical activity to accumulate in large bodies, is one of other circumstances which point to the same conclusion. Since the waters were endowed with great dissolving power in a short space of time, they were probably greatly heated. The fact that the mineralization clings so closely to the porphyry indicates that the waters were either derived from the igneous rock or, at least, had a common origin with it; the minerals which the waters deposited are such as would be derived from the porphyry.

These phenomena coincide with those which are most typical of the studied cases of contact metamorphism, and this appears to furnish the best explanation for the origin of the deposits. Briefly, the water which accompanied and was perhaps the motive cause of the eruption was separated from the lava at the moment of cooling and found its way into the adjoining rock. Being still intensely heated, and carrying in solution many of the chief elements of the eruptive mass, it exerted for a comparatively brief period a powerful altering force on the easily soluble limestone, and in the course of this alteration the ores were deposited. The deposition of the crystalline calcite veins may be assumed to have marked the final stage of this action, when the waters were much diminished in quantity, cooled, and deprived of the corrosive agents which they originally held in solution. At this latter period the currents, instead of tending always away from the contact into the limestone, may often have been reversed, and have introduced lime to fill up the cavities.

CHAPTER III.

THE GOLD LEDGE.

The gold-bearing horizon in the vicinity of Mercur and Marion hills lies a short distance above the Silver ledge. On Mercur Hill, according to the statement of Mr. R. C. Hills,[1] which is confirmed by the observations of the writer, the gold-bearing horizon is about 150 feet above the top of the Silver ledge. On Marion Hill it appears to be considerably less, the average distance between the two deposits, as shown by the difference of altitude between the Carrie Steele and the Marion workings, being, according to the detailed survey of Mr. Frank Anderson, approximately 100 feet. In this latter locality, however, there are a multitude of small faults, which make the actual difference between the two horizons rather uncertain.

Like the Silver ledge, the Gold ledge follows a sheet of Eagle Hill porphyry, of slight thickness and usually in greatly decomposed condition. Owing to this decomposition, it is not easily recognized as porphyry, nor even as an igneous rock; indeed, its true nature was first detected by the writer only after he had been some little time in the field. The field evidence of its nature may be briefly indicated as follows:

1. The general megascopic character of the decomposed rock of the gold horizon, especially where only slightly or not at all mineralized, is exactly that typical of altered porphyries as exhibited at other mining districts, such as Leadville. There is a superficial difference, owing to the great dryness of the climate at Mercur; for this reason the altered porphyry does not usually contain any water, and hence does not assume the clay-like form known as "talc" by the miners.

2. This altered porphyry in the gold horizon is identical in appearance and characters with the altered porphyry of those portions of the Silver ledge below which have escaped the effects of the Silver ledge mineralization.

3. This zone can be traced continuously from the above-named hills along the outcrops in either direction, but especially to the southwest, through the various stages of less alteration to the comparatively fresh rock which contains phenocrysts and has a firm consistency and rough texture. This unaltered rock is part of the main sheet of Eagle Hill porphyry, which apparently owes its fresh condition to its greater thickness and consequent freedom from weathering except along the edges.

[1] Ore deposits of Camp Floyd district, p. 3.

Into this same main lower sheet the altered porphyry of the Silver ledge can be followed.

Microscopic study has supported the conclusion derived from field evidence, in showing that the altered rock of the Gold and Silver ledges is a decomposed porphyry identical with the porphyry of the main sheet. This conclusion has already been stated in the preceding chapter, namely, that the main sheet of Eagle Hill porphyry splits, just southwest of Mercur Hill, into three thin sheets, of which the lowest is the thickest and the uppermost the thinnest; and that the lowest is characterized by the occurrence of silver ores, while the gold ores are confined to the middle of the three, and the uppermost has not been mineralized to any important extent.

The gold of the ore is invariably invisible, no one ever having claimed to have found a grain of the metal; the richness or entire barrenness of a sample, therefore, can be gauged only by assays. When richest, the ore generally has a loose, pulverulent gangue, which consists mainly of quartz. Associated with it is arsenic in the form of realgar; also cinnabar and iron pyrites. Barite, calcite, gypsum, and Chinese talc are found in the ores, but are not believed to be closely connected genetically with the gold mineralization.

Recent atmospheric changes have altered those of the gold ores which are most exposed, so that there are two distinct classes, considerably different in the nature of the rock and the mineralogical character of the ores, as well as in their economic importance. Among the unoxidized ores, those on the property of the Golden Gate Mining Company are the most important so far discovered. The exploration there has been very slight, so that there is no good opportunity to study this important class of ores; but as the sulphides are plainly the original form of all the ores, it will be necessary to describe their occurrence in the Golden Gate.

GOLDEN GATE MINE.

The explorations on the Golden Gate property at the time of examination consisted chiefly of two shafts, a short distance apart, a little above the town—the north or Mabel shaft, and the south or Grasshopper shaft.

MABEL SHAFT.

The north shaft of the Golden Gate is about 136 feet deep. It starts on an outcrop of the barren limestone which lies above the ore-bearing zone, and continues in it down to the bottom of the shaft; the ore is encountered in a drift leading southward from the bottom. The material exposed in the shaft, which is not timbered (the dryness of the climate renders very little timbering necessary in this district), is limestone, often considerably decomposed, and evidently broken and disturbed. The average dip in the shaft seems to be about 15° southwest.

The drift at the bottom runs a little east of southeast, across the strike and in the direction of the dip. This drift is 127 feet long. It starts in

limestone, which is hard in places, but in others is somewhat decomposed, probably by surface agencies. At a little distance from the shaft there appears in the drift a more altered zone in the limestone. This is siliceous and broken, and is somewhat mineralized, forming a low quality of ore. Above this is a zone of altered limestone, but softer and containing less silica than the one just mentioned. It yields easily to the pick or hammer, and probably a large part of its lime is replaced by silica in incoherent grains. There is some pyrite and a small quantity of gold, but less than that of the broken zone below. Following this is an actual thickness of about 6 feet of the cherty and broken, altered limestone, like that first mentioned. This is also a low-grade ore, of about the same value as the first. Above this again is an actual thickness of about 10 or 15 feet of altered limestone, dark-gray in color, and still retaining the characteristic structure, rough in texture and crumbling easily. Although considerably altered, this appears to be only slightly mineralized, and contains little gold. At the end of the drift a raise goes up vertically 22 feet, which near the bottom runs into a soft, black, fissile rock resembling shale, and so termed by the miners. It is somewhat different from the dark-gray altered limestone below, although of the same color, and, like it, is soft. The rock in the raise is smoother in texture, and is more markedly fissile. This fissile structure, however, is probably not an evidence of original stratification. It is rather of that nonpersistent, slightly irregular variety which is so common in residual as well as in sedimentary clays, and which often owes its origin to causes operating since its formation. This rock is, from the top to the bottom, greatly mineralized, being especially marked by the abundance of realgar; it contains also a considerable quantity of finely disseminated iron pyrites, and a much larger amount of gold than any in the lower zones, averaging probably half an ounce to the ton of ore. At the top of the raise the shale gives place rather suddenly to a hard, blue, unaltered limestone, which is absolutely barren. Of this only about a foot is exposed. There is here, therefore, a very fairly defined zone of ore about 20 feet in thickness.

GRASSHOPPER SHAFT.

The south shaft has a depth of 64 feet. For 46 feet from the top it is in limestone, which is somewhat broken and shows the effects of surface disintegration; it then cuts ore of the oxidized type, such as is found in the Mercur and the Marion mines. This ore is soft and pulverulent, light yellowish or grayish in color, and contains no pyrite, realgar, or other evidence of mineralization. The presence of gold is shown only by assay. The ore is about 10 feet thick; in the drift a few feet away it is found to actually pass into unoxidized sulphide ore, from which it is therefore directly derived. The bottom of the shaft is in limestone under the ore. This rock is somewhat broken and decomposed, has a northwest strike, and a dip of 20° or 25° to the northeast.

A drift running northwest from the shaft cuts, in a short distance, a sulphide ore exactly like that in the Mabel shaft, and containing a very large amount of realgar. The thickness also is about that of the ore in the Mabel, so that it is evidently the same sheet, and is probably continuous between the two localities. The drift runs through the zone of ore into hard limestone above, and at the end a raise goes up 40 feet without finding any change in the character of the rock. There appear to be rather more bands of hard material in the ore here than in the north shaft.

The so-called "black shale" in the Golden Gate mine, with which the ores are associated, probably results, in part at least, from alteration of the thin sheet of porphyry before mentioned. It is on the same horizon as the other ore deposits, and the analysis of the Golden Gate ore (p. 424) shows a considerable amount of the alkalies, indicating the presence of feldspathic constituents, such as are contained in porphyry.

From the Golden Gate shafts the outcrop of the gold ledge has been followed southward nearly continuously, and is marked by shallow prospect holes. It shows a small amount of mineralization for most of the way up Mercur Hill as far as the Mercur mine. Although the oxidized rock is undoubtedly more profoundly altered from its original condition than that which contains the sulphide ores, yet in the latter the process of mineralization and the deposition of the sulphides have evidently had a disguising effect, making the difference between the altered porphyry and the altered limestone unapparent without careful study, so much are the original characters of both replaced by the characters induced by the mineralization which both alike have undergone. But with oxidation most of the sulphide ores, especially the abundant arsenic-sulphide and pyrite, are decomposed and leached out, so that the original difference between the porphyry and the limestone is better shown, though it is by no means always clear. It is for this reason that the outcrop of the Gold ledge porphyry can be followed with a certain degree of ease, and for this reason also the oxidized ores offer quite as favorable opportunities for study as do the sulphide ores from which they are derived. It is in these oxidized ores, moreover, that most of the exploitation work has been done, since they are easily reduced. They readily yield up their content of gold to the dissolving influence of cyanide of potassium, and from these solutions it is precipitated by metallic zinc. Such is the condition of the gold in the sulphide ores, however, that the cyanide solutions are comparatively ineffective. The sulphur must first be driven off by roasting, which is practically equivalent to the slow natural process of weathering, and in this roasting there is said to be a marked loss of gold. For this reason their reduction on a large scale has not yet been attempted, though probably they will be mined and successfully treated in the future.

In the oxidized ores a large amount of mining has been done in the Mercur mine up to the present time; indeed, larger than all the other workings in the district. In this mine, therefore, most of the data in

MAP OF UNDERGROUND WORKINGS OF MERCUR MINE.

Figures denote elevations referred to datum at mouth of Ruby Tunnel, assumed as 6,000 feet

Scale: 75 feet = 1 inch.

regard to the detailed structure of the gold deposit have been obtained, the owners and superintendent having lent their aid in every way to its full investigation. The Mercur ore bodies will therefore be described in considerable detail.

MERCUR MINE.[1]

UNCLE SAM TUNNEL.

This is the most southerly in the series of tunnels in the Mercur mine which have been or are actually productive of ore. The mine is

FIG. 42.—Banding in altered porphyry.

opened by means of these tunnels, which are driven into the side of the hill at the outcrop of the altered zone along the strike of the beds. The mouths of the tunnels, viewed from a distance, afford a very good indication of the position of the ore sheet.

At the entrance to the Uncle Sam tunnel the open cut shows at the top a thickness of 4 or 5 feet of soft, shaly stuff, of various alternating shades of brown, gray, and yellow. This is undoubtedly altered Eagle

[1] Geological sections through the principal workings of this mine may be found on Pl. XXXIV, p. 418.

Hill porphyry. It is the characteristic roof of the ore sheet, and among the miners goes by the name of "shale." Immediately below this altered porphyry zone comes decomposed limestone, containing about one-third in bulk of soft, pulverulent stuff, which incloses bowlders of hard, blue lime and of chert, making up the other two-thirds of the rock. The bowlders have been formed in place by decomposition extending from the fissures and joint and bedding planes inward; and the gray pulverulent matter which surrounds them is the product of their alteration. It is very much like the product of the alteration which takes place under atmospheric influences, such as has already been noted in the general description of the limestones of the district. There is only about 5 feet in which the proportion of the altered to the unattacked limestone is as above indicated, for the alteration grows less as the distance from the porphyry increases. The limestone gradually becomes more massive, and the rounded bowlders give place to large square blocks, separated by narrow zones of decomposition, some of which run parallel with the bedding and some perpendicular to it. The strike of the limestone here is about N. 55° W., and the dip is 12° NE. In the least-altered limestone at the bottom of the cut are numerous empty fissures, vertical, and averaging in direction about N. 30° E., although varying from N. 10° E. to N. 60° E. These range from mere cracks to fissures 2 inches wide. They do not exist in the altered limestone, but their continuation can often be traced through it by lines of greater decomposition than the rest of the rock. In the decomposed, yellow, shale-like rock above there is no evidence of them. That these fissures are not of very recent origin, such, for example, as might be caused in surface rocks by blasting in the process of excavation, is shown by the fact that there is commonly on their walls a thin coating of crystalline calcite. Thus, in one fissure, at a point where it is an inch in width, there is a coating of calcite on either side, between one-sixteenth and one-eighth inch thick.

At 25 feet from the mouth of the tunnel the shaly stuff loses its fissile character, becoming massive and divided by planes of fracture into blocks. It is still soft, however, and bears evidence of great decomposition. It is generally stained yellowish, with occasional residual patches of light gray. In some zones, however, it becomes thin-banded and much broken, as in the outcrop. It seems, therefore, that the shaly and banded variety of this altered porphyry is directly due to oxidation at the surface, and that the massive form is more nearly the original; and the residual patches of gray material recall the "black shale" of the sulphide ores. As a matter of fact, there are in this mine, as will be seen later, many places where the process of oxidation is actually going on, by which a dark-gray ore carrying sulphides, in every way identical with the ore of the Golden Gate, is changed to the light-gray massive variety or to the banded, light-colored, fissile rock.

The zone of altered porphyry, although in a general way conformable with the bedding of the limestone, shows many local irregularities; so that the contact rolls up and down along the course of the tunnel, while the general direction of the limestone remains constant. Near the mouth of the tunnel the contact curves down across the bedding from the roof almost to the floor, and after running along on a level for a short distance, curves upward again and disappears above the roof, just beyond the first cross-cut to the east, which leads to the Nimrod stopes. At this point the altered limestone, with its characteristic decomposition bowlders, is not present, but the massive altered

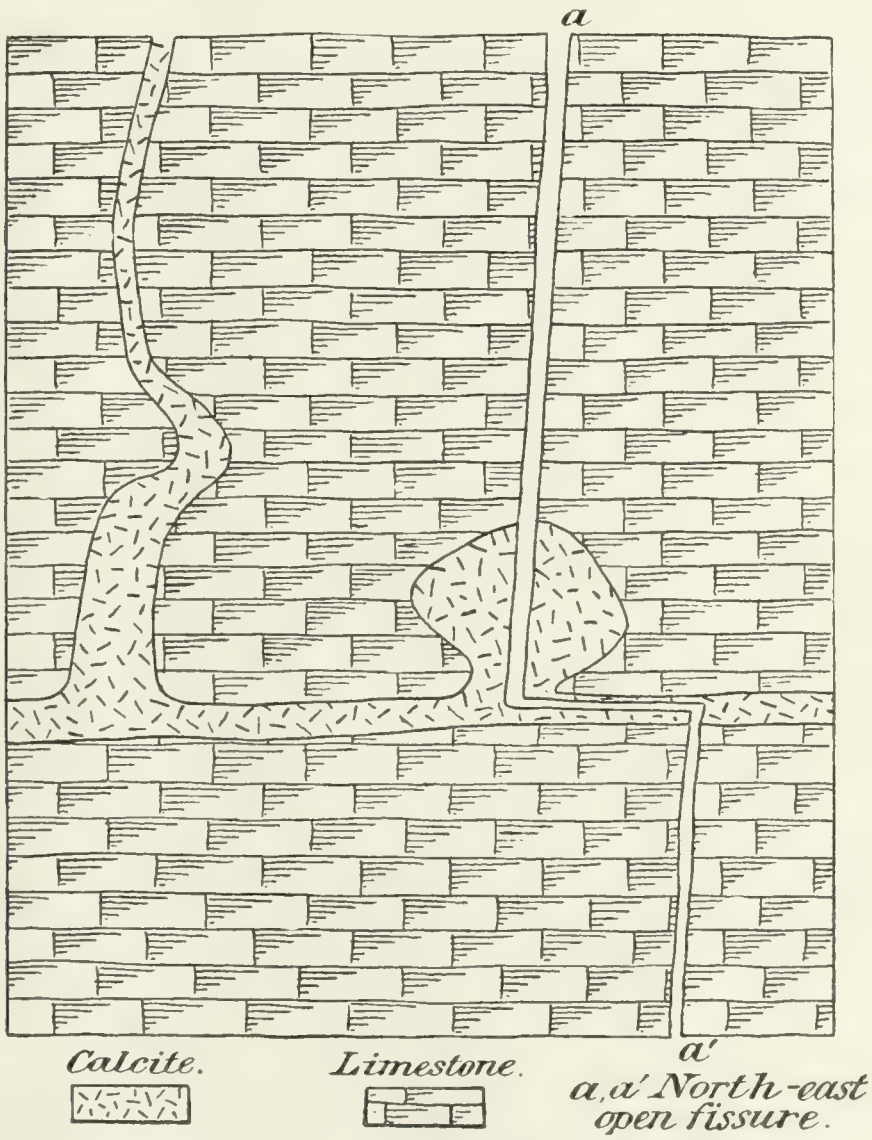


FIG. 43.—Open fissure cutting and deflected by calcite vein.

porphyry rests directly upon comparatively fresh limestone, containing vertical northeast open fissures. Besides these open fissures there is a distinct set of fractures which are filled with crystalline calcite, and which evidently belong to an earlier period of formation. Wherever these two sets of fractures occur together, not only in this mine but anywhere else in the district, the same relation in point of age is noticed between them. The older are entirely filled with coarsely crystalline

calcite, and appear in general to be nonpersistent. The smaller are simply gash veins, and may be seen to thin out and disappear at both ends on the walls of the drifts. The larger are often 2 or 3 inches wide, and in places along their course bulge out into irregular shapes, as if waters which coursed along the fissures had here fashioned spaces by their corrosive power alone. These irregular spaces may be a foot or more in diameter. The veins vary in trend from about N. 10° W to N. 60° E., but average N. 20° E. in trend, and hade about 80° W.

The empty cracks and fissures mark a period of sheeting of the rock which was evidently posterior to the formation of the calcite veins just described. In trend and hade these later fissures are approximately similar to the calcite veins; but they are much more persistent in their nature, since they usually run from the top to the bottom of the drift, with no evidence of diminishing in either direction. Some of the smaller cracks have quite bare walls, but there is usually a thin coating of calcite, with small crystals projecting inward from either wall. This lining usually takes up only a very small portion of the space, so that nine-tenths of the crevice is empty, although in the smaller ones often much less. The paucity of the calcite and its irregular distribution, as well as its thicker deposition at the opening of small, irregular crevices in the limestone which run into the main fissure, show that it has been deposited under comparatively dry conditions. The fissures often follow along the course of a calcite vein, this evidently offering a zone of less resistance to the second strain. Sometimes the crack runs in the middle of the calcite, but more often on the side, so that on one side of the later fissure is the limestone wall and on the other the older vein. Sometimes, also, the crevice cuts through one of the large, irregular spaces of calcite which have been described as connected with the veins. (See fig. 43.) These phenomena are mentioned as showing the later age of the open fissures.

In the stopes on both sides of the main tunnel, ore has been taken out, usually from a point about 10 feet below the altered porphyry to the top of it, stopping at the hard limestone above. The thickness of this altered porphyry here is not far from 15 feet, so that the total thickness of rock removed is 25 feet. Often, however, it has been taken out only as far up as the bottom of the altered porphyry or "shale," which often constitutes the roof, so that here the thickness of material removed is only about 10 feet. The chief ore, therefore, is that somewhat decomposed zone of limestone, often containing bowlders of decomposition, which immediately underlies the altered porphyry. In some places this contains considerable chert; in others, no more than the ordinary limestones of the district. Above, the altered porphyry may be sometimes richly enough impregnated with gold to be available as ore, but hitherto this has quite as often not been the case. Usually the mining stops at the lower contact of the altered porphyry, leaving a clean and quite regular wall; and in every case it must stop at the upper contact of the porphyry with the limestone,

and this in turn gives an even wall, for the limestone is generally quite barren. Below, the mineralization extends irregularly and gradually into the limestone, and therefore the floor of the ore bodies, as shown by the excavations, is irregular. The average thickness of available ore is perhaps about 7 feet.

NIMROD NO. 2 TUNNEL.

The stopes near the mouth of this tunnel, which is next to the Uncle Sam, proceeding along the outcrop down the hill, connect on one side with the Uncle Sam stopes and on the other with the stopes of the Nimrod tunnel. The general structure here is the same as described in the Uncle Sam stopes. The bleached and altered porphyry is sometimes shale-like and sometimes massive, and averages 8 or 10 feet in thickness. Below it the limestone is often altered to a soft and crumbling condition, yet in places is still massive and of a light-brown color, so that it is very much like the altered porphyry in appearance. A convenient distinction between the altered porphyry and the altered lime, stone is the presence in the latter of small calcite veins, which are never found in the porphyry. This limestone is profoundly fractured by the same system of fissures that has been described in the Uncle Sam tunnel as northeast in trend and vertical in hade. So great is the fracturing throughout this whole tunnel that it is difficult to get the actual strike and dip.

A short distance from the mouth of the tunnel the same upward roll that was noticed in the Uncle Sam carries the decomposed ore-bearing horizon up above the drift, which passes into the hard limestone beneath. In the latter rock are some very large northeast open fissures, which are persistent from the top to the bottom of the exposure, and which, on account of the freshness of the rock, are very clearly defined. There are also some calcite veins having the same general direction, but they are rarely persistent along the whole height of the tunnel. At about 100 feet from the mouth is an intensely fractured zone, along which there is a most interesting alteration, and one which throws much light on the processes of mineralization. This zone is vertical and about 10 feet thick. It is characterized by a soft, black, massive rock, like much of that associated with the ore, and which the miners call black shale. This has no trace of horizontal structure, but in places the fractures have given it the semblance of vertical bedding. In the softer parts the fissures have been filled by the products of decomposition, and yet they can usually be traced without much difficulty; along the sides of some of the more open of them are almost continuous coatings of realgar. This soft, siliceous rock becomes recognizable in its harder portions as a softened and altered limestone, and on either side of the strongly fractured zone it so grades into hard limestone that it is impossible to locate any boundary between the two. It is evident that in this case the limestone is altered into one phase of the

"black shale" which in the unoxidized condition contains the ore, and although no assay was made from this particular place, the presence of abundant arsenic and the results of other assays made later from similar localities show that this also is probably an ore. The flat-lying ore horizon, with the altered porphyry for a roof, is out of sight, above the top of the tunnel, and this vertical tongue of ore extends from the flat-lying zone downward into the limestone. It evidently follows a set of the open northeast fractures, which mark a strongly sheeted zone, and the mineralizing agents have followed this zone, depositing the characteristic sulphides of the gold horizon and changing the limestone to the "black shale," which is the typical gangue of the unaltered ore.

At about 185 feet from the mouth the tunnel turns and runs nearly at right angles to its former course. Just before turning the corner, a raise shows, about 15 feet above, the massive light-colored rock, often banded red and yellow, which is probably the altered porphyry; at the turn the altered porphyry comes down into the tunnel, and stopes lead down to the Nimrod workings. The limestone below this is broken and cherty, and the contact between it and the altered porphyry is sharp. The porphyry itself shows all the different varieties which are found connected with the ore. Much of it is massive and black, very slightly fissile. This variety is hardly distinguishable from the rock of similar appearance which is derived from the limestone by alteration; and, as in the Golden Gate mine, the explanation must be that the same process of mineralization, and the deposition in both of the same minerals, have made from these two originally dissimilar rocks products which appear to the eye almost exactly alike. Here there are patches and irregular bands of light brown, which appear to be residual, since they are often surrounded by the soft black rock. In many other places the black rock is surrounded by the light-yellow rock, with red and greenish bandings, which has before been noted as characteristic of the altered and bleached porphyry of the Gold ledge. One place shows beautiful, nearly vertical, red and yellow bandings, trending northeast, or parallel to the general direction of the fracturing. There appear to be here, then, the three most typical stages in the alteration of the porphyry as found at the horizon of the gold ores: First, the light-brown, massive, somewhat decomposed variety, which outcrops along this horizon in places where it has not been mineralized, and is similar to the altered Eagle Hill porphyry at other horizons. Second, the dark-gray "black shale" of the miners, which sometimes surrounds the first type and is evidently derived from it. As already stated, this rock is due to the processes of mineralization. The analysis by Dr. Hillebrand of dark ore like this discloses the presence of a considerable amount of finely divided and disseminated iron pyrites, in such fine particles as often to be megascopically invisible, and this probably gives, in part at least, the black color to the rock. This pyrite was probably introduced at the

time of mineralization, and accompanies the gold and other characteristic minerals. Third, the type which is so common in the oxidized zone of the gold ores, the light-colored banded variety. The derivation of this variety from the massive, black, mineralized rock just discussed has been observed in innumerable places, and is seen to be due simply to the effects of surface oxidation, whereby the sulphides are decomposed, partly leached away, and partly concentrated as oxides in the irregular bands which sometimes give it the simulation of bedding. This simulation, however, is destroyed on the slightest attentive observation, for the bands are rarely horizontal for any distance, or even continuous in any one direction, but become curved and sinuous, often being arranged in concentric circles (see fig. 42). The bands are, therefore, simply the concentration of some of the colored oxides in zones of slight weakness formed in the rock by the contraction attendant on the loss of a part of its bulk by weathering.

Toward the end the tunnel follows several narrow and nonpersistent streaks of soft, decomposed material in the hard limestone below the main ore-horizon. These streaks fade out into the hard limestone in all directions, and are evidently due to its decomposition, in the same manner as are the vertical zones along the fracture planes. They are here, however, very slightly or not at all mineralized.

NIMROD TUNNEL.

This follows the same horizon, next the Nimrod No. 2 tunnel. The entrance is in the broken limestone which lies under the altered porphyry, but in a short distance a roll in the porphyry brings the latter down into the tunnel. In raises it appears to be in thin sheets, with altered limestone and chert between, and hard, brown, altered limestone above, which soon changes to the blue unaltered rock.

In the first raise, on the right hand, are found barite veins in the altered cherty rock. Although these are numerous, they have no predominant direction; they are not persistent, but form irregular bunches, and penetrate the rock in every direction, being entirely similar in habit to the barite in the Silver ledge. Like the rock in which they are found, these veins appear to be considerably decomposed. They crumble easily, and are inclosed in a gray powder, which seems to be the product of the decomposition of the limestone in which they were once embedded. This powder, falling out, very often leaves the crystals of barite entirely isolated. As this decomposition evidently accompanied the introduction of gold in the ores, the barite could not have been deposited at the same time, but must have existed in the rock prior to this mineralization. On the other hand, it has every indication of an origin similar to that of the barite of the Silver ledge, and may well have been deposited at the same period.

The shale is partly black, partly light and banded. The limestone immediately below is so broken that neither bedding, distinct fracture

planes, nor any other structure can be made out. It is much altered, with bowlders of residual hard limestone, and has the appearance of being good ore. Beyond the stopes it becomes harder, and it is then seen to be traversed by many vertical northeast open fissures. In places there are also many small, nonpersistent calcite veins, which sometimes carry realgar. This is rarely the case where the vein is already quite full of calcite; but where the calcite has only partly filled the fracture, or where a solid vein has been traversed by a later crack, realgar is found forming a coating upon the calcite, on both sides of the fracture. In one case noted a calcite vein was cut at right angles by a narrow open fissure, the sides of which were coated with realgar. This coating extended through the calcite vein, but the rest of the calcite carried none of it.

At the end of one of the barren drifts a flash-light photograph was taken, showing a very perfect set of the persistent open fissures in the hard limestone. (See Pl. XXXII.) They are here in their general north course; the walls are nearly straight, and bear little evidence of corrosion or erosion. The limestone near a large fracture is generally so much sheeted that it falls out easily, and to this the widening of the original sheeted zones is probably due, rather than to any dissolving action subsequent to the formation. It is not probable that at the time of formation these zones offered any such large open spaces as at present, when some of them are wide enough to admit an arm. The walls of these fissures are sometimes crusted with gypsum, and with calcite, from which the alteration to gypsum is to be observed. These crusts are not continuous; and their formation by slow exudation under comparatively dry conditions, rather than by deposition from freely circulating waters, is shown by the fact that wherever a slight crack having a different course from that of the fissure runs into it its junction with the main fissure is marked by a slight but prominent ridge of botryoidal calcite, while the adjoining surface has only a mere film. On these ridges the outside is usually gypsum and the inside calcite, although sometimes it is all gypsum.

From the stopes the main tunnel runs below the ore horizon into a hard blue limestone containing calcite veins. At some distance it enters a vertical zone of ore, similar to the one described in Nimrod No. 2 tunnel, but more extensive. Here the tunnel turns, and follows this zone to the breast. The altered rock is marked by multitudinous parallel fractures, running about N. 30° W., a direction somewhat different from the ordinary trend, and dipping 75° SW. Along these fractures the limestone has been completely altered, for a width of about 5 feet, to the typical "black shale" of the gold ores. In some places, moreover, it has been oxidized to the light-colored, banded variety, the bands being commonly parallel to the direction of the sheeting. The cracks, fissures, and small interspaces are filled with realgar. On both sides of this altered zone is the hard, little-altered limestone, and in

FACE OF DRIFT IN MERCUR MINE.

Showing fissures in hard limestone of Gold horizon.

some cases a single strongly marked vertical fracture separates the hard limestone from the soft arsenical rock. The calcite veins which occur in the hard limestone are present in the altered zone, but they are entirely changed to gypsum. In some cases a vein which is at one end entirely of gypsum passes out of the altered zone and becomes at the other end of pure calcite. Residual bowlders of the hard limestone are occasionally found in the very midst of the soft ore. As the tunnel follows this zone, the alteration and mineralization gradually decrease, till at the breast it has nearly disappeared. The fissures are still present, and wider than before, and it may be due to this fact that there is no mineralization along them. Observation in various parts of the mine show that where these fissures are the widest the mineralization is generally very small. On the contrary, it is in places where the rock is greatly sheeted and the individual fissures are narrow that the mineralization has been greatest. It is as if the agents which produced this result were detained in the passages where the circulation was less easy, while they passed so rapidly through the larger canals that they had little effect. The fissures at the breast of the tunnel trend about N. 10° W., showing a return toward the more usual direction, and have a hade of about 75° W.

At about one-third of the distance from the point where the tunnel runs into the mineralized zone to the breast a raise has gone up on the vein for about 50 feet. It was found that the mineralization became less along this raise, so that it was discontinued. It is not impossible, however, that a continuation of it would have revealed the existence of a larger body of ore above.

In the Nimrod stopes, which are very extensive, ore has been taken out in a continuous sheet, varying considerably in thickness. This irregularity is due mostly to the irregularity of the mineralization in the limestone which constitutes the floor; the roof is in general uniform.

MERCUR TUNNEL.

This tunnel adjoins the Nimrod on the east. It starts in the somewhat broken and altered blue limestone, at a little distance below the chief ore horizon. About 20 feet above the mouth there is an open cut (see Plate XXXIII), exposing the characteristic gold-bearing horizon. Here is seen the thin sheet of altered porphyry, bleached and almost crumbling, and below it the altered limestone, consisting of gray powder, which incloses decomposition bowlders of harder rock. A small tunnel connects this open cut with the Mercur stopes.

The altered porphyry comes down into the roof of the main tunnel at a point about 40 feet from the mouth; below this is broken and cherty limestone. At about 100 feet there are in this cherty limestone many large veins of barite, some of them nearly a foot wide. They are characteristically parallel with the bedding, although some of the smaller ones are vertical, and many spread out through the rock in no

particular direction. The largest are at the contact of the altered limestone and the altered porphyry; none were seen to enter the porphyry. The cherty rock and the character of the barite veins strongly suggest the Silver ledge, although the chert is broken and somewhat decomposed, and seems to have undergone a later alteration, which is evidently that of the Gold ledge mineralization. In many of the veins open cavities are found, into which the crystals of barite project. These were, perhaps, formed by the decomposition of a part of the limestone which originally filled them, or they may have been left at the time of the deposition of the barite; this latter condition is often found in the unaltered barite of the Silver ledge. On the walls of these cavities cinnabar is often found in small quantities lying upon the crystals of barite. It seems probable that at the time of the secondary mineralization these minerals were deposited on the barite where open cavities already existed, and that the barite itself was formed at the time of the primary mineralization which produced the ores of the Silver ledge.

Farther on there are many small calcite veins in the limestone, but they all terminate abruptly on reaching the altered porphyry. This limestone is not so broken or so cherty as near the mouth of the tunnel, where the barite veins are found. For a considerable distance there is exposed at the bottom of the tunnel about a foot of hard blue limestone, which lies under the most altered and mineralized zone. This is traversed by vertical fractures, and along the bedding planes often becomes soft and black; it also carries a small quantity of realgar. At about this point a winze goes down 50 feet in hard, unaltered limestone, showing that the mineralization does not extend downward. From here the tunnel runs on in generally hard limestone, always apparently below the main ore sheet; but in a short distance a turn in its course brings it nearer the ore horizon, and the limestone begins to be irregularly altered in places to the arsenical ore, yet without any brecciation or any change in the attitude of the beds. Every stage of the change from the solid, hard limestone to the soft, decomposed material, which is identical with a large part of the "black shale" of the main ore horizon, can be traced; but in this case these softer portions are usually surrounded on all sides by the hard limestone. Predominant fractures trend N. 10° E., and dip 75° W., and their walls are generally coated with arsenic. Farther on, the whole rock is mainly changed to the decomposed variety, which still carries realgar and some cinnabar, but is massive and has no fissile structure. Farther on still, the zone of broken and cherty limestone, which is typical of the ore belt, comes in over the soft, altered limestone; and yet farther, the light-colored massive rock, which probably represents the altered porphyry, comes in in its usual place above the cherty zone. A change in the direction of the tunnel with reference to the course of the porphyry causes the porphyry to rise again to the roof and disappear within a few yards.

OPEN CUT ON GOLD LEDGE, MERCUR HILL, NEAR NIMROD TUNNEL.

Then comes, in the reverse order, the same succession which has been described: first, the zone of broken and cherty limestone, and then the soft, black, arsenical, altered limestone. There is of this about 15 feet. The contact then rises, and the tunnel runs for 50 feet with the altered limestone above and the hard blue limestone below. The rock above carries gypsum veins, while that below contains veins of calcite, and often one runs directly into the other, showing that the gypsum has been formed by alteration of the calcite, as the soft rock has been formed by alteration of the limestone. In some cases a crack whose sides are coated with realgar traverses a vein of gypsum; sometimes a realgar vein of this sort may pass through both gypsum and calcite. This does not necessarily show that the gypsum was formed as a vein before the introduction of the realgar, but only that the calcite veins were formed earlier than those fissures which carry realgar.

In the stopes connected with the Mercur tunnel neither the altered porphyry nor the altered limestone is fissile, both being massive or pulverulent. In that part of the stopes which is nearest the surface and which connects by a short tunnel with the open cut above mentioned, there is exposed about 5 feet of altered porphyry, brown in color and broken into irregular blocks, which by weathering have become marked with usually concentric bands of brighter color. Above this is altered limestone, some of it entirely decomposed to a gray powder; below, the limestone is altered in the same manner, with harder residual bowlders inclosed, which are sometimes of unaltered blue limestone. This altered limestone carries considerable earthy, scarlet cinnabar, and is a very good gold ore.

APEX TUNNEL.

This tunnel starts in above the ore, in hard blue limestone, somewhat fractured, and runs into the ore horizon at a distance of about 50 feet. At this point stopes about 10 feet high run under the floor of the main tunnel. Above is a brown, massive rock, which may be the altered porphyry, and below this is exposed 5 or 6 feet of broken cherty limestone, carrying barite in irregular, generally horizontal, veins. Farther on the ore horizon rises gradually, so that it passes above the roof of the drift. The great stopes at the end of the main tunnel are all in hard and little-altered limestone, with only small areas of decomposition along some of the joint and bedding planes. It is, nevertheless, a very good ore. None of the soft, altered, arsenical limestone is present, and none of the altered porphyry; the roof and the floor present no especial difference from the stoped-out rock. It seems very possible that the altered porphyry and the cherty zone which mark the typical ore-bearing horizon may be above the roof of the stopes. With this idea in view, a sample was taken of the limestone at various points on the roof, as far up as any material could be obtained. This was assayed by Mr. R. H. Officer and gave 0.82 ounce of gold to the ton, an ore

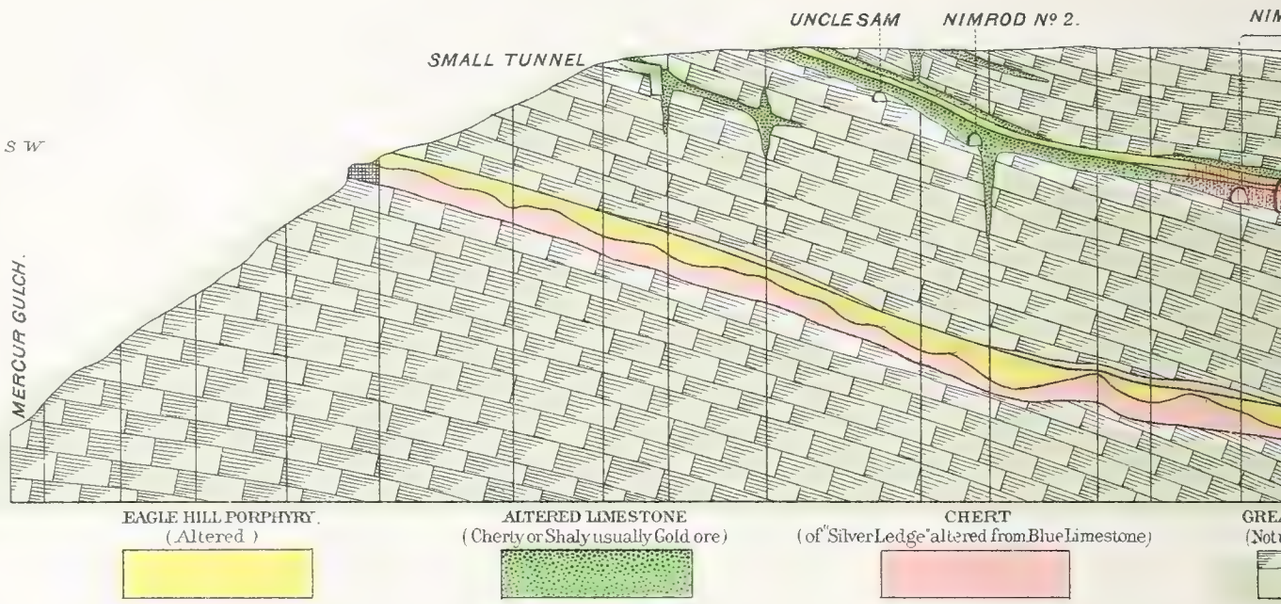
fully up to the average of the mine. Below the point from which this sample was taken the ore has already been stoped out for an average thickness of about 10 feet, and continuously along this same horizon for some distance, except for pillars which are left standing to afford support to the roof.

Going up in the stopes toward the Mercur tunnel, we meet, near the tunnel, the cherty horizon again, which here carries considerable Chinese talc, entirely similar in nature and habit to that already noted in the Silver ledge. The stopes which run under the Mercur tunnel near its mouth, down to the Resolute tunnel, also contain, associated with the cherty material, considerable Chinese talc, along with cinnabar and some barite.

RESOLUTE TUNNEL.

This tunnel starts on the gold horizon, in the cherty zone. Near the mouth are many vertical open fractures, trending N. 20° E. At a distance of about 50 feet from the mouth is a light-gray, massive rock, several feet thick, which is probably an altered porphyry; it is well shown in the drift which runs down toward the Ruby tunnel. Immediately beyond the junction of this with the main drift the contact suddenly rises into the roof, and is not seen again in the tunnel. Just beyond this point the stopes begin, and ore has been taken out on the western side from the level of the tunnel floor up to a height of from 6 to 20 feet. Nowhere does the roof seem to be the decomposed porphyry which probably lies above, but a very slightly altered blue limestone, similar to the rock which has been stoped out. This seems to be a trifle below the normal ore horizon. Immediately after leaving the stopes, and proceeding farther into the tunnel, hard blue limestone is encountered, occasionally a little softened and carrying narrow vertical veins of realgar. The strike and dip here are respectively about N. 55° W. and 20° NE., but both are often obscured by vertical fractures, which are very numerous and persistent, and along which are sometimes found the coatings of realgar just mentioned. They vary in trend from N. 10° E. to N. 60° E. and dip about 70° NW. At the last Resolute stopes, which connect with the Apex stopes, a small quantity of ore has been taken out; overhead is a soft, irregularly decomposed rock, which is evidently an altered limestone, and not the altered porphyry that constitutes the true roof of the ore in general. If the altered porphyry is present it must be above the roof of the stopes.

From this point to the end of the main tunnel there is continuously hard blue limestone, without chert, but with frequent softer, decomposed patches of irregular shape, which grade into the unaltered limestone on all sides, and carry arsenic sulphide. In this limestone there are always northeast open fractures; there are also generally northeast-trending calcite veins, which are characteristically nonpersistent; but no barite. The latter mineral has been observed only in the cherty horizon directly underlying the altered porphyry.



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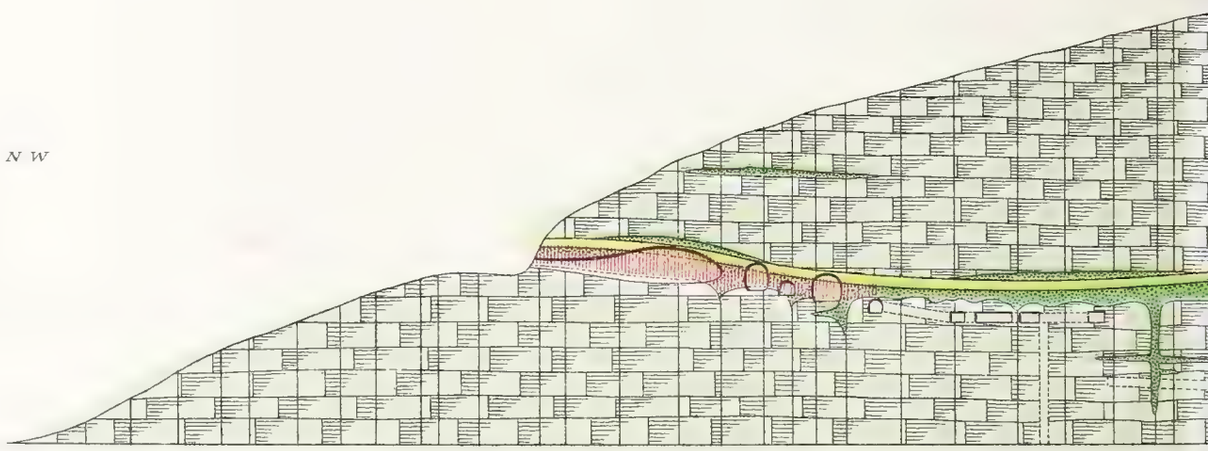

SECTION C-C.

Horizont

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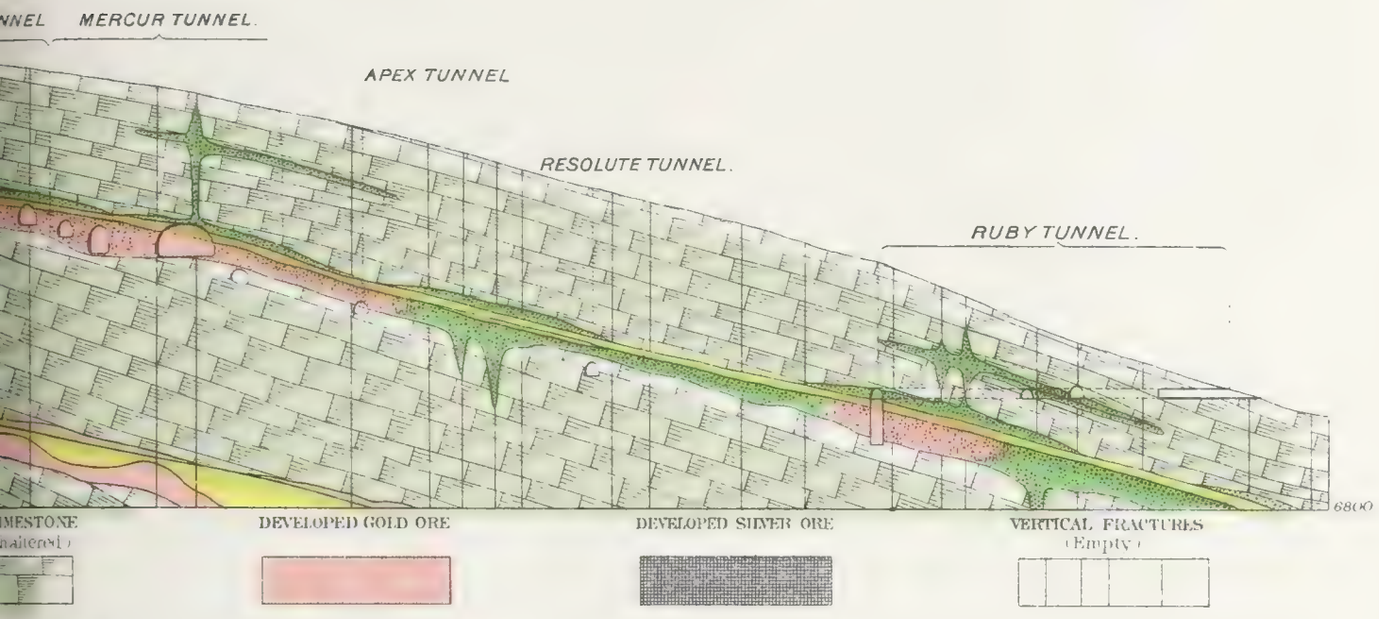
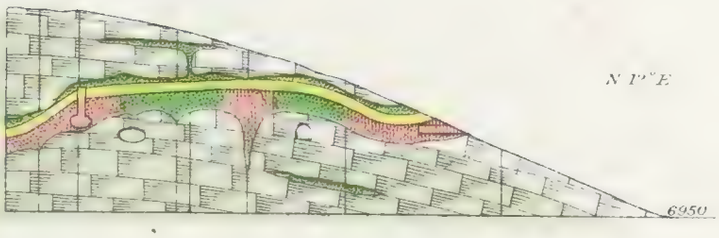


ON A-A.

GEOLOGICAL SECTIONS
OF THE
MERCUR MINE
Based on the MERCUR MINE MAP.



ITE T

SECTION B-B.

Vertical Scale
200 200 feet

JULIUS BIEN & CO LITH N Y

RUBY TUNNEL.

In the incline which connects the Resolute with the Ruby tunnel the altered porphyry is shown in the walls, dipping at a slightly greater angle than the inclination of the drift. At the sudden turn in the incline this altered porphyry runs below the floor. From here to the main Ruby tunnel the incline is in altered limestone, very soft and shale-like in streaks.

The Ruby tunnel appears to have been started at a considerable distance above the main ore horizon. At some distance in, it cuts a streak of ore running conformably with the bedding. This streak is not very thick, and does not seem persistent. It is characterized by a very much decomposed gray rock, sometimes fissile and sometimes massive, which is probably an altered streak in the limestone, the result of the mineralizing solutions which have penetrated along the bedding planes; it may, however, represent a thin sheet of altered porphyry, and so be more similar to the main ore body. Some ore has been taken out of this streak, but it does not seem to pay for extensive stoping. The limestone below is broken and altered, and above it shows a fissile tendency. Level drifts which run in the direction of the Resolute tunnel show the ore streak rising to the roof and disappearing; and the limestone below becomes hard and unaltered, with many nonpersistent calcite veins, and open vertical fractures having a general trend of N. 10° E. At the end of one of these westerly-running drifts a winze has been sunk which reveals what is probably the main ore horizon. At a short distance below the floor of the drift is light-gray clay several feet thick, which is probably altered porphyry; below this is soft, black, arsenical rock, which is evidently an altered limestone. In this the winze goes down about 20 feet.

In the main tunnel the small ore streak which the tunnel follows rises to the roof after some distance and disappears. At the end the main tunnel is in hard limestone, and a winze has been sunk which reached the main ore horizon at a depth of 35 feet. This consists of a slight thickness of altered limestone, soft and black. Below this is 5 or 6 feet of light-colored clay, which is probably altered porphyry; and below this again the broken and cherty lime which constitutes, here as well as elsewhere, the chief ore-bearing zone.

MARION MINE.

The Marion mine was not examined with the same detail as was the Mercur, since there was no especial difference in the phenomena exhibited in the two; moreover, on account of impending litigation, the same facilities for investigating the mine could not be obtained. The following is the result of a brief examination:

The roof of the ore deposit can be traced nearly continuously, and can be recognized as an altered porphyry, less changed on the whole

than in the Mercur mine; it is sometimes shaly in structure, oftener massive. The thickness of this altered porphyry varies from 2 to 20 feet; on the average it is about 5 or 6 feet. According to Foreman Jones, there is never any ore of importance above this zone, but sometimes the porphyry itself is sufficiently mineralized to be mined. As in the Mercur, the chief ore is the zone of cherty limestone immediately below the porphyry sheet. This is about 6 or 7 feet in thickness, and as a rule it is rather more altered than in the Mercur. In one place observed this limestone is comparatively barren of gold values, although altered and cherty and in every way resembling the actual ore, and although the usual roof of altered porphyry is directly overhead.

The most interesting point of difference between the Mercur and the Marion ore bodies lies in the even greater importance of the northeast fractures in the latter. The fracture zones are very abundant, and along many of them there has been a slight faulting. In all there are in the mine probably thirty or forty well-defined faults, varying in throw from 2 or 3 to 40 or 50 feet, the latter in one or two places only. In nearly every case the ore, instead of being cut off, follows the fault zone up or down to the corresponding horizon on the other side.

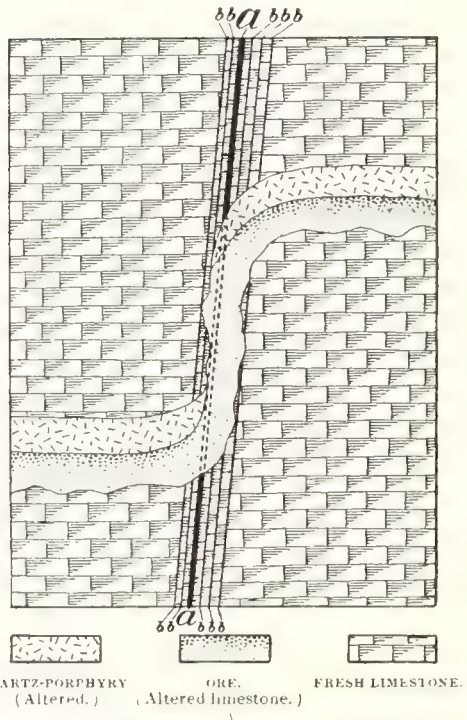


FIG. 44.—Diagram showing relation of ore to fault in Tunnel No. 3, Marion mine. *a*, *a*, chief fault plane; *b*, *b*, parallel fissures. Scale: 1 inch = 40 feet.

This is well exemplified in a fault seen in Tunnel No. 3. At the point examined this fault had a throw of about 40 feet, but according to Foreman Jones the throw is differential, being considerably greater at one end than at the other. All along the fault ore has been taken out for a width of 6 or 7 feet, leaving an open fissure connecting the flat-lying ore in the No. 3 workings with the flat-lying ore 40 feet above, in No. 2 tunnel, on the other side of the break. The fault zone is nearly vertical, and trends at this point about N. 70° E. The sheet of altered porphyry and the cherty limestone are cut off at the lower level and do not reappear until the other side of the fault is reached in No. 2 tunnel. The vertical zone which connects the two levels has not, therefore, all the usual characteristics of the ore. It is simply a softened and mineralized limestone, with hard blue limestone on both sides. Several places in the mine were noted which show the same phenomenon of mineralization along fracture or fault zones. This occurrence of ore is similar to that in the mineralized vertical zones in the Mercur, which also follow zones of sheeting, and differs chiefly in the fact that in the Marion the fractures are attended by notable displacement. Here the

mineralization appears not to extend into the sheeted fault zone above or below the normal ore horizon on either side of the fault, but simply connects the two parts which have been separated by the faulting. The limestone above and below the part of the fault thus mineralized is much harder, and the individual fractures in it can be seen, which in the more altered portion have been filled by the products of disintegration.

As a general rule the ore in the fault fissures is of a poorer quality than that under the regular wall of altered porphyry. Its chief value, therefore, seems to be that it affords an indication of the direction of the ore horizon when it is broken by a fault; and thus is avoided much of the expense entailed in vain search for faulted ore bodies, such as is inevitable in most mines where a considerable degree of disturbance has taken place.

It does not seem probable that the ore in the fault zone represents part of that originally present in the normal ore horizon and which was simply dragged into the fractured zone at the time of the faulting. Its character is not such as to favor this hypothesis, being rather that of limestone which has been altered in place than that of brecciated material foreign to the wall rocks. The ore is apparently of about the same thickness and quality throughout the whole of the vertical zone; whereas, if it was derived from the flat-lying horizon and had been brought up along the fault, one would expect it to be thickest at either end, near the junction with the beds from which it was derived, and in the middle to be poorer or even absent. The inference, therefore, is that the mineralization which introduced the gold in this mine took place after the series of northeast fractures and the accompanying faults were developed; this is also the inference derived from the study of the relation of the ore to the open fissures of the same kind in the Mercur mine.

One large fissure in the Marion mine, along which no displacement has been noted, is several feet wide, but the most of this space has subsequently been filled by crystalline calcite. Since the deposition of the calcite there has been a further fracturing, as is shown by the existence of a large open fissure between the vein calcite and the limestone wall rock. In this later fissure the calcite on the vein side has assumed a very beautiful stalactitic structure. The same fissure extends downward into the Silver ledge in the workings of the Carrie Steele. Here it has been explored for some distance, the opening being large enough to easily admit a man. No ore of importance, however, has been found along this opening.

Some barite is found in the Marion gold ores, especially in cherty portions; also Chinese talc in similar localities. Cinnabar is frequent in the much-altered ore. Most of it is the bright-red, earthy variety, like that in the Mercur mine and elsewhere; a single specimen shows the dark-red, crystalline variety. This is the only specimen of crystal-

line cinnabar which was found in the vicinity of Mercur, and from its peculiar condition and the relations that it sustains to the calcite with which it is associated there is reason to believe that its age and the conditions of its deposition are different from those of the usual form of cinnabar. This special case will be mentioned later. (See p. 451.) Realgar was found forming crusts on calcite in veins which were not entirely filled, but retained a narrow open space in the middle. These veins occur chiefly in the hard blue limestone which underlies the ore.

GEYSER MINE.

The Geyser workings are situated on the northeast side of Marion Hill, on the same horizon as the Marion workings, but at a slightly lower elevation, owing to the dip of the porphyry sheet, which in both cases forms the roof. The ore revealed by these explorations is said to be of good quality, but up to the time of writing no gold has been extracted.

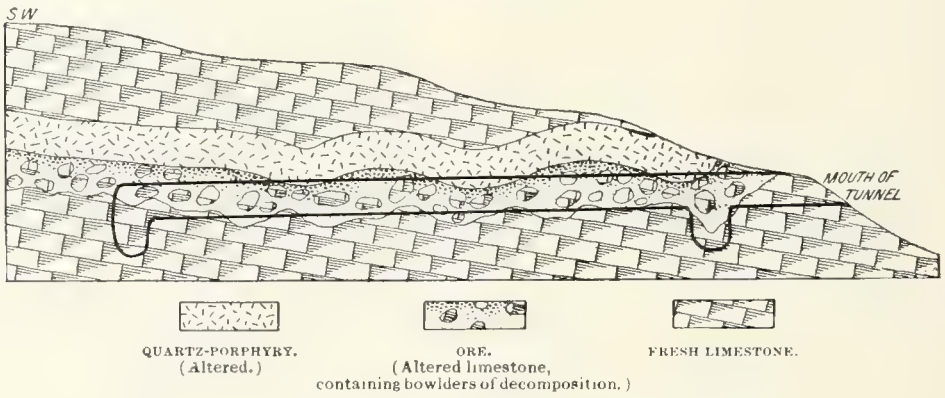


FIG. 45.—Section along Geyser tunnel. Scale: 1 inch = 40 feet.

In the open cut at the mouth of the main Geyser tunnel there is exposed the hard blue limestone, which at this point lies under the ore. The mouth of the tunnel itself is at the contact of altered porphyry and somewhat altered but still mainly hard limestone; the latter constitutes the ore, as elsewhere. The porphyry runs in a general way parallel to the bedding of the limestone, but locally often cuts across the bedding for a few feet, so that the actual contact is very wavy. The difference between the trough and crest of these waves is about 5 or 6 feet, and several are cut in the course of the tunnel. The very bottom of the porphyry is stained yellow and green for a few inches, and constitutes a low-grade ore. Above this zone it is massive and pearl-gray and shows only a trace of gold. Below the porphyry comes a broken contact zone, consisting mainly of brecciated limestone often silicified. There also appears to be a certain amount of altered porphyry in the breccia. This is the main ore body, which follows continuously the lower contact of the porphyry sheet and is said to be on the average about 12 feet thick. Below this zone there is usually a

thin selvage band of altered shale-like limestone, which does not exceed 6 inches in thickness. This contains a little gold, but by no means enough to be classed as an ore. Below this is the same hard blue limestone as is exposed at the open cut, and this is quite barren. It will be seen from this description that the lower contact of the ore appears to be more sharply defined than is usual, and yet it is much more irregular than is the upper contact.

SURPRISE SHAFT.

The Surprise shaft is the deepest vertical working in the camp, and is a good example of the fact that not all of the ore horizon is mineralized, for while it has undoubtedly passed through the horizon along which the ore occurs in the Mercur and Golden Gate, all the rock thus far encountered has been practically barren.

The shaft starts in the lower shale belt and passes through this down into the hard limestone. The water which runs along the shale on top of the limestone accumulates in the bottom of the shaft to a depth of 30 or 40 feet even in the dry season. This is the only mine in the camp which contains water. Below the bottom of the shale, however, no water enters the workings.

Upper level.—At 125 feet from the top the first level runs off in a northwesterly direction (N. 25° W.) for 277 feet. Along the bottom of the drift is exposed a foot or so of altered porphyry like that in the other mines, but harder than in some. This is also exposed in the shaft below the floor of the drift, and is about 6 or 8 feet thick. Above the porphyry in the drift is decomposed limestone, stained and full of chert lenticules and nodules. This is the exact counterpart of the ore in the productive mines, but assays only a trace in gold. In the top of the drift is a thin streak of soft, shale-like rock, sometimes containing fragments of chert; this also seems to be decomposed porphyry. Immediately above this is hard blue limestone.

Lower level.—At 342 feet from the top a level runs in a generally northwest direction for about 100 feet. At the top of the drift is porphyry, decomposed and flaky; below this, at the mouth of the drift, is pulverulent altered limestone, stained green and yellow and containing much chert. This also is in all respects like the typical ore in appearance, but assays only a trace. At the bottom of the drift the limestone becomes very hard. The porphyry sheet is probably 4 or 5 feet in thickness; at the end of the drift a raise goes up 21 feet across the sheet, which shows an apparent pinching out. Below this drift hard limestone extends all the way to the bottom of the shaft.

RELATION OF THE SULPHIDE TO THE OXIDIZED ORES.

That the oxidized ores are derived from the sulphides by a simple process of weathering is a fact supported by abundant field evidence. In the Grasshopper shaft of the Golden Gate mine, as already stated,

there appears a zone of ore in the oxidized condition, and farther down, in the drift leading from the bottom of the shaft, the same zone is encountered in the condition of sulphide. There are many places in the Mercur mine where a covering of the oxidized ore incloses a residuary portion containing sulphides, and the gradual stages of the transition are clearly shown.

ANALYSIS OF SULPHIDE ORE.

Following is a complete analysis of the sulphide ore from the Grasshopper shaft of the Golden Gate mine, by Dr. W. F. Hillebrand:

Analysis of Golden Gate ore.

	Per cent.
Silicon dioxide (SiO_2)	66.42
Titanium dioxide (TiO_2)	.85
Aluminum sesquioxide (Al_2O_3)	14.85
Iron sesquioxide (Fe_2O_3) } Iron protoxide (FeO) }	.31
Iron disulphide (FeS_2)	6.60
Manganese oxide (MnO)	None.
Calcium oxide (CaO)	.35
Strontium oxide (SrO)	None.
Barium oxide (BaO)	.19
Magnesium oxide (MgO)	.83
Potassium oxide (K_2O)	2.73
Sodium oxide (Na_2O)	.13
Lithium oxide (LiO)	(*a*)
Water below 110° C	.53
Water above 110° C	3.65
Sulphur trioxide (SO_3)	.31
Phosphorus pentoxide (P_2O_5)	.04
Antimony pentoxide (Sb_2O_5)	None.
Arsenic pentoxide (As_2O_5)	.41
Arsenic disulphide (As_2S_2)	1.75
Molybdenum (Mo)	None.
Tellurium (Te)	*b* Trace (?)
Total	99.95

a Very strong trace.
b In the opinion of Dr. Hillebrand there was tellurium in the sample analyzed, although on account of the small quantity obtained he was unable to submit it to a special test, and therefore thought best to indicate this lack of certainty by the interrogation mark.

In its main elements this analysis is like that of an altered porphyry, differing chiefly in its content of arsenic and the traces of the rarer metals. The amount of alumina and the considerable quantity of potash and soda indicate the presence of a considerably altered orthoclase feldspar, while the magnesium and a part at least of the iron may well be derived from biotite. Leaving the arsenic out of consideration, the analysis can be almost exactly paralleled by the analyses of somewhat altered porphyries from other places, such as the White porphyry of Leadville. This bears out the result of field observations on the character of the ores in the Golden Gate mine already mentioned. According to these observations, some of the black sulphide ore of the Golden Gate is an altered limestone, while a part at least is an altered porphyry, and decomposition and the influence of the same mineralizing processes have given to both a common appearance, so that they can

not be readily distinguished in the hand specimen. It was evidently from the altered and mineralized porphyry that the specimen analyzed was taken.

In examining the analysis a few things only are found which can not be referred for their source to the porphyry. The chief of these is the arsenic, which is evidently of subsequent and foreign origin, and which is here, as in the hand specimen, the chief indicator of the mineralization. In the hand specimen every little crevice is filled with this brilliant mineral, which occasionally becomes so abundant as to form the greater part of the bulk of a good-sized specimen. Ordinarily the appearance is not as if the realgar had replaced the country rock into which it has intruded, but as if the rock, shrunken from the effects of decomposition and the leaching out of a part of its volume, had afforded in its interspaces opportunity for the arsenic to crystallize. The specimen which was taken for analysis, however, was not one which appeared in the hand specimen to be rich in arsenic; that which was found may be regarded, therefore, as an average rather than an extraordinary amount. Undoubtedly all the arsenic was deposited as sulphide, and the small amount of oxide is therefore to be taken as the result of the alteration processes, which even in the sulphide ores have already begun. Besides the arsenic, the presence of a probable trace of tellurium is suggestive of the mineralization.

The amount of iron in the rock, chiefly in the condition of sulphide, but with a small amount changed to oxide, is not sufficiently great to justify the conclusion that it has a foreign origin identical with that of the arsenic. It is true that the fact that both are in the form of sulphides indicates that they were both reduced to this form at the same time and by the same agents; but this fact can be used quite as effectually to support one theory as another. There are no large bodies of pyrite in the ores; even aggregations of small size are rare. The mineral is disseminated in very small crystals throughout the ore, of which it therefore forms a generally inconspicuous part. It is far less characteristic of the mineralized rock than is the arsenic. The amount shown in the analysis may therefore be taken as a fair average of the content of the ores, and a corresponding amount of iron is not infrequently found in fresh porphyries, being contained in the biotite and other dark-colored silicates. Since in this case much of the most easily soluble elements, such as the potash and soda of the feldspars, has not been leached out, it is only natural that the iron of the original rock should remain, although as a result of the decomposition and the mineralizing agents it has been separated from the silicates and again concentrated in the form of sulphide.

ANALYSIS OF OXIDIZED ORE.

Following is the result of the analysis by Dr. Hillebrand of a sample of the oxidized gold ore, taken from the stopes of the Apex tunnel in the Mercur mine. This is in every way a typical sample of the best class of the oxidized ore.

Analysis of Mercur ore.

	Per cent.
Silicon dioxide (SiO_2)	89.24
Titanium dioxide (TiO_2)	.38
Aluminum sesquioxide (Al_2O_3)	2.02
Iron sesquioxide (Fe_2O_3)	1.45
Iron protoxide (FeO)	.62
Iron disulphide (FeS_2)	None.
Manganese oxide (MnO)	None.
Calcium oxide (CaO)	.95
Strontium oxide (SrO)	None.
Barium oxide (BaO)	.72
Magnesium oxide (MgO)	.23
Potassium oxide (K_2O)	.47
Sodium oxide (Na_2O)	.08
Lithium oxide (LiO)	(*a*)
Water below 110° C	.56
Water above 110° C	1.16
Sulphur trioxide (SO_3)	.44
Phosphorus pentoxide (P_2O_5)	.08
Antimony pentoxide (Sb_2O_5)	None.
Arsenic pentoxide (As_2O_5)	1.60
Arsenic disulphide (As_2S_2)	None.
Molybdenum (Mo)	(?)
Tellurium (Te)	(?)
Total	100.00

a Strong trace.

Except for the fact that the Silver ledge ore is characterized by the presence of considerable antimony and little arsenic, and the gold ore by considerable arsenic and no antimony, the foregoing analysis is very much like that of the silver ore from the Sparrowhawk, which has already been given (p. 394). It shows a considerable degree of difference from the analysis of the unoxidized ore from the Golden Gate. A large part of the difference between the two varieties of gold ore comes, of course, from the oxidation, but it is not fair to assume that the alteration is sufficient to account for all of the changes. In the case of the ore from the Mercur stopes the rock is evidently an altered limestone, while that from the Golden Gate is an altered porphyry, and these original differences show very clearly through the effects of the mineralization.

On the other hand, the gold ore of the Apex stopes and the silver ore from the Sparrowhawk are both the result of the alteration of similar limestones, and hence the general similarity of their chemical composition. It is in the differing nature of the rarer metals which they contain, and which are most closely connected with the mineralization, that the difference in the character of the ores and of the mineralizing processes is indicated. In the same way, the relation between the Golden Gate and the Mercur ores is not indicated by the general

analysis, but by the presence of the same rare element in both, viz, abundant arsenic, and by the entire absence of antimony.

Judging from the physical characters of the ores, their relationship as above indicated is not to be mistaken. The ores are divided by every miner at first sight into two classes which do not resemble each other, those containing silver and those containing gold. There is only one class of silver ore, for the oxidizable materials are not abundant enough to make any material change in the appearance of the ore when weathered. The ore remains massive and siliceous, with dark-gray color, typically brecciated appearance, and ramifying veins of calcite and barite. On the other hand, the gold ores are friable and even pulverulent, for the grains are not firmly compacted in the unoxidized state, and become almost entirely incoherent on weathering. The color and consistency have procured for the latter the popular name of shale, which in many cases they strongly resemble. On oxidation this color quickly disappears, and is replaced by a light tint, usually pearl-gray or cream-yellow, and there arises a striking but irregular banding, sometimes horizontal, but usually curved and often concentric, from the concentration of the iron of the oxidized pyrite along lines of greater weakness than the rest of the rock. (See figs. 42 and 47, pp. 407, 444.) But in both the oxidized and the sulphide ores the general characters are much the same, and the oxidation produces a change in constituents which make up only a small part of the rock rather than a complete change in its general nature.

IRON.

The analysis of the specimen of sulphide ore shows 6.60 per cent of pyrite and only 0.31 per cent of iron oxides, the latter being probably due to the incipient oxidation of the pyrite. In the analysis of the oxidized ore we find that the pyrite has entirely disappeared, and the rock contains only 2.07 per cent of the iron oxides. Allowing for the difference in the weight caused by the substitution of oxygen for the heavier sulphur in combination with the iron, there still remains in the weathered ore less than half the quantity of iron which exists in unoxidized form. If we assume that before the oxidation both ores had approximately the same amount of iron, it follows that a part has been removed in the process of oxidation. What remains is chiefly in the form of the sesquioxide, probably hydrous, and has segregated into the red and yellow bands which distinguish the oxidized ore. Most of the iron protoxide is probably in the form of iron sulphate, being combined with the sulphur trioxide recorded in the analysis. This salt is readily soluble, and being a common product of the oxidation of pyrite is undoubtedly the form in which much of the iron has been removed from the rock. That iron sulphate in solution is actually present in the rock is shown by the formation on the walls of drifts which cut the black sulphide ore of large quantities of the fine, colorless, astringent-tasting crystals of melanterite, which is crystallized

iron sulphate. This mineral is very common, being especially noted in one of the Protective Tariff tunnels and in one of the smaller tunnels of the Mercur mine.

ARSENIC.

In the unoxidized ore arsenic is mainly in the form of the sulphide, realgar, and, as in the case of the iron, that portion which is in the form of oxide undoubtedly represents the product of incipient decomposition. In the oxidized ore the sulphide has totally disappeared, but most of the arsenic remains in the form of pentoxide. It is probable that a large part of this pentoxide is in combination with other elements, chiefly iron. A characteristic of the oxidized ores is a light-green stain or thin film, which is found in all the crevices of the rock and which gives the green color to many of the segregated bands. Some of this mineral was examined chemically and found to be a hydrous ferric arsenate, probably scorodite. A large part of the arsenic pentoxide in the rock may be combined in the form of this and similar minerals, and in this combination may be included a part of the iron derived from the oxidization of the pyrites. Since these arsenates are readily soluble under certain conditions, they are found distributed pretty generally throughout the ores, and even leached down into the rock beneath.

MERCURY.

The amount of mercury in the ores is probably not so great as one at first might suppose. In neither of the specimens of gold ore was it possible to find any positive trace of the metal, although special tests were made. This is rather remarkable, for the sample of oxidized ore was taken from the Apex stopes at a locality where specimens of the bright-red, earthy cinnabar are frequent. The fact that there was none in the specimen analyzed shows that the metal is probably sporadically concentrated in these oxidized ores. If, then, the rock which does not show cinnabar to the naked eye is barren of the mineral, the small concentrations which are frequently encountered will amount to a very small percentage of the whole rock. In the early days, when the district figured as a silver producer and when what is now mined for gold was exploited for mercury, it was claimed that the ore in some places averaged 4 per cent, but this seems to be very improbable.

In the sulphide ores no cinnabar can ordinarily be found. Mr. R. C. Hills mentions finding it in the Golden Gate mine "only in very small specks, scarcely noticeable without a lens." The presence of a large amount of mercury in the Golden Gate ore is reported from sundry sources, but these reports are not considered reliable by the owners. It is probable that the metal exists in the sulphide ores in small quantity, finely disseminated throughout, but what its form is is not definitely known. The small specks of earthy cinnabar, as well as the larger quantity in the oxidized ores, are probably the result of the alteration of some other form. It seems certain that it has undergone

some change, for it is a mineral highly susceptible to varying conditions and could not remain unaltered during the oxidation of the arsenic and the iron.

Around many of the small rounded pellets of cinnabar in the oxidized ores is a small amount of a grayish-black mineral with metallic luster. In most cases the relation of the cinnabar to the black mineral is such as to suggest that the cinnabar is the older of the two, from which the other has been derived; but occasionally, especially in small grains seen by incident light under the microscope, it seems possible that the reverse is the case. In some places the black mineral forms the larger part of a small pellet, with only a little cinnabar in the center; but more often it appears to form a very slight crust on the outside of the cinnabar. It is never so abundant as to be conspicuous in the hand specimen, being well observed only with the aid of a magnifying glass. Enough of this mineral could not be obtained for analysis, but tests show that it is not metacinnabarite, the black sulphide of mercury, as its association at first suggested. Tests for selenium were also made, it being suspected that the mineral might be tiemannite or some other selenide, but without result. In thin sections of the unaltered sulphide ores of the Golden Gate mine small irregular grains of what appeared to be the same mineral were observed, so situated as to seem to have crystallized at the same time as the realgar. It is possible that this is the original form of all the mercury.

GOLD.

That some change in the nature of the gold is brought about by oxidation is shown by the difference in the behavior of the sulphide and the oxidized ores. In the latter the gold is readily soluble in potassium cyanide, and is thus extracted, while in the former it is only slightly soluble. In neither the sulphide nor the oxidized ore has the form of the gold been determined. It exists in both in a very finely divided condition, for particles are never large enough to be detected by the naked eye, or, up to this time, by the microscope. From the solubility of the gold in the oxidized ores in potassium cyanide, it has been supposed to be in the free state, for the power of this cyanide to dissolve the finely divided metal is well known. Judging by the same criterion, the gold in the sulphide ores is not in the state of the simple metal—at least, such as we know it. It also appears that the gold is not especially associated with any of the sulphides which accompany it, and therefore the theory that it may be in the native condition, but protected from the action of solvents by the inclosing minerals, is not probable.

The fact that in the sulphide ore gold is no more abundant in the realgar than in the rest of the material has been shown by comparative assaying. Mr. R. C. Hills[1] states that samples of Mercur ore rich in

[1] Ore deposits of Camp Floyd district, p. 9.

realgar often prove on assay to contain little more than traces of gold; and he also records that Dr. Richard Pearce "carefully separated some of the realgar from a sample of Golden Gate ore, the former affording only a trace of gold, though a previous assay of the ore itself had demonstrated its fair average value." Mr. R. H. Officer and Mr. J. W. Neill, of Salt Lake City, have made the following experiments for the purpose of determining this fact. A selected piece of ore from the Golden Gate mine, which was mainly solid realgar, was assayed and found to contain 0.07 ounce of gold to the ton. Next, a portion of the same specimen was roasted and the arsenic completely driven off. The nonvolatile residue constituted 16 per cent of the original specimen. It was siliceous in nature and light-gray in color. This residue proved on assay to contain 0.35 ounce of gold to the ton. Similar results were reached in assays made especially for the Survey. A sample of Golden Gate ore which was selected as being particularly rich in arsenic, containing probably 50 to 75 per cent of realgar, was found to contain gold in the ratio of 0.42 ounce to the ton. This is not above the probable average of all the ores of the Golden Gate. Subsequently a similar specimen was ground, and by means of sieves those grains having a diameter of between one-fortieth and one-sixtieth of an inch were separated from the rest. These were then put into a Thoulet solution having a specific gravity of 2.85. That which sank appeared under the hand lens to be nearly pure realgar, and was assayed, giving a result of 0.50 ounce to the ton of ore. All these experiments show that, although in a general way the presence of arsenic in the unoxidized ores is a favorable sign for the existence of gold, as being an indicator of the mineralization which introduced both elements, yet the two are not always closely associated in the deposits.

Neither has there been found any close association between the cinnabar and the gold. The same general relation which has been described for the realgar holds good for the cinnabar, and this relation appears to be closer than in the case of the former mineral, for those portions of the ore which contain cinnabar are almost invariably of good value, and often are especially rich. But attempts to discover an intimate connection between gold and mercury have been unsuccessful. Mr. R. C. Hills mentions that assays of selected samples containing a high percentage of cinnabar "gave only from $5 to $6 per ton in gold, indicating that only a small portion of the metal in the ore was contained in that mineral."[1] Likewise, a specimen taken from portions of the Mercur ore especially rich in cinnabar was examined in the laboratory of the Survey, and found to contain gold in the proportion of 0.40 ounce to the ton, worth about $8.

Messrs. Officer and Neill have made the following experiments to determine the significance of pyrite in the sulphide ores: First, a sample of black shale containing pyrite was taken from the lower and

[1] Ore deposits of Camp Floyd district, supra cit.

lesser water-bearing zone which is cut in the Surprise shaft. This fossiliferous and truly sedimentary shale never contains more than a trace of gold, so far as observation has gone, and is thus to be distinguished from the so-called "black shale," which is really altered limestone and porphyry. The latter is also pyritiferous and is characteristic of the ore horizon. The pyrite concentrated from the sample of water-bearing shale gave only a trace of gold on assaying. Second, from a sample of Golden Gate ore which assayed $11 (0.55 ounce) to the ton, the pyrite was concentrated by panning. That panned out was about 1 per cent of the total weight of the ore, and assayed $44 (2.20 ounces) to the ton.

The results of this last experiment are not convincing in either direction. On the one hand, the pyrite which was panned out of the rock was found to have a content of gold four times as large as that of the rock in general. On the other hand, it formed a very small part of the total weight of the rock, and so contained a very small proportion of its value. In a ton of the ore, for example, there would be $11 worth of gold, while in the 1 per cent of pyrite contained therein there would be $0.44 worth, and the balance, or $10.56 worth, is in the residue. If, therefore, all or even a large part of the whole amount of pyrite was removed from the ore in this experiment, it indicates that the gold, although owing to chemical relations it has an affinity for iron, was originally deposited and still continues mainly independent of it.

Mr. Hills in his paper suggests the possibility that the gold occurs in combination with tellurium. Owing to the small quantity of gold, which averages hardly over half an ounce in the ton of ore, and is never known by the writer to have exceeded 3 ounces, chemical investigation on this subject has been unsatisfactory, no gold having been detected by wet analysis. If the gold is in the state of telluride, therefore, it is only by concentration and elaborate analyses that this can be fully proved. But the analyses already given show that tellurium does exist in the Mercur ores. Curiously, however, the most pronounced trace was found in the silver ore of the Sparrowhawk mine, where both tellurium and molybdenum are present, probably in the fully oxidized state. There is a very small amount of gold in the Sparrowhawk ores, one assay showing 0.035 ounce to the ton, and another a trace, but the amount is probably not sufficient to account for the presence of tellurium in the analysis. It may then be assumed either that the tellurium was originally present in the Silver ledge in other forms than in combination with gold, or that, on the decomposition of gold tellurides in the gold ore above, the freed tellurous acid, which is readily soluble in alkaline waters, was leached down into the silver ores below. This is the origin that has been suggested for the oxidized arsenic in the silver ores of the same mine.

In the sulphide ore from the Golden Gate mine no molybdenum was found, but a probable trace of tellurium. No test for tellurium was made of the oxidized ores, but they probably contain small quantities

of tellurium in the fully oxidized state. Even a trace of tellurium in so small an amount of ore as must necessarily be taken for analysis is sufficient to unite with the gold, which also occurs in very small quantities. The insolubility of the sulphide ore in the cyanide solution and the solubility in the same of the oxidized ore is consistent with this idea. Telluride of gold is not readily attacked by the cyanide, but on oxidation breaks up, forming native gold and tellurous acid, and the gold can then be dissolved in the solution. Results similar to this are obtained by roasting the sulphide ore of the Golden Gate. Messrs. Neill and Officer found that, after roasting, about 63 per cent of the gold could be leached out by cyanide; in roasting, however, there was a loss of gold varying up to 13 per cent. This constant loss in roasting is significant as to the probable form of the gold, for such loss is usually much greater in the tellurides than in other ores.

While, therefore, it is as yet not proved in what condition the gold may be, the evidence is most favorable toward the hypothesis that it is in its original form a telluride, very finely disseminated; and that, on oxidation by natural processes or by roasting, it becomes free gold.

CONDITION OF THE GOLD IN THE OXIDIZED ORES.

It seems most probable that the gold exists in the oxidized ores in the free state, but in a very finely divided condition, and probably in a form somewhat different from that of ordinary metallic gold. The gold obtained by precipitation from solution is a fine powder, black, brown, purple, or red in color, without metallic luster. This amorphous gold offers various points of difference from the yellow, ordinary variety, which have been summed up by Mr. Henry Louis in a paper read before the American Institute of Mining Engineers.[1] Thomsen had shown that the behavior of amorphous gold when acted upon by chlorine or bromine is different from that of ordinary gold; in the first instance aurylic compounds (Au_2Cl_4 or Au_2Br_4), and in the second auric salts ($AuCl_3$ or $AuBr_3$) are produced. Mr. Louis states that the two varieties have also a different density, although there is every stage of gradation between the two extremes. Another point of difference brought out by his investigations is in their behavior toward mercury. The readiness of the common form of gold to form an amalgam with mercury is one of the best-known properties of the metal, since it is so extensively used in the treatment of ores. But gold precipitated from highly dilute solutions by means of ferrous sulphate is not at all attacked by mercury when freshly precipitated, and only slightly when dried. While indifferent to mercury, this gold is in a form in which it is readily attacked by chlorine and potassic cyanide. Mr. Louis makes the following provisional deductions from his investigations:

"1. Gold is capable of existing in allotropic modifications.

[1] The Allotropism of Gold, Trans. Am. Inst. Min. Eng. Vol. XXIV, 1894, p. 182.

"2. One of these modifications is capable of amalgamation with great difficulty, if at all.

"3. This modification is capable of being produced and of subsisting under conditions which may be reasonably supposed to exist in nature when gold is deposited in reefs."

In the Mercur oxidized ore the gold has the same peculiarities as are here indicated for the supposed allotropic form. As already stated, all attempts to extract it by amalgamation have proved failures, only a very small portion of the metal being concentrated by this means, while the results of treatment with the solution of cyanide of potassium are very satisfactory. As a purely theoretical reason it may be added that if, as suggested below, the gold has been affected during the process of oxidation, having been taken into solution by alkaline waters and precipitated by the ferrous sulphate derived from the oxidation of the pyrite, it would then be in the amorphous form which is indifferent to mercury, as shown by the laboratory experiments mentioned above.

FORMATION OF SULPHATES.

The oxidation of the iron pyrites has resulted in large part in the formation of hydrous ferrous sulphate, which crystallizes out in considerable quantity on the walls of newly opened drifts in ore not entirely oxidized. This mineral, melanterite, occurs in many fine, colorless prisms, which dissolve readily in the mouth, leaving a peculiar astringent taste. On account of its ready solubility it is not permanent, and is therefore not found in portions of the ore which have been completely oxidized.

The conversion of calcite to gypsum is another of the results effected by soluble sulphates resulting from the oxidation of the sulphides. The detailed evidence of this transformation has been given in the description of the Mercur mine. It is in certain regions where circulation is the freest, such as the preexisting vertical fissures and sheeted zones, that this change has chiefly gone on. On such a zone a vein of gypsum is often found in softened and altered limestone, which becomes transformed into a vein of calcite on entering the hard and unchanged rock.

NATIVE SULPHUR.

In the Mercur district as mapped no native sulphur has been found. According to Mr. A. H. Holden, of Salt Lake City, it is found in the oxidized portions of the Sunshine mines, which lie a few miles to the south of Mercur. These mines are on the contact with the same general sheet of porphyry as at Mercur, and undoubtedly have a similar origin. The production of sulphur is probably due to the reduction of sulphides with scanty access of oxygen; freer access of oxygen produces sulphuric acid and the sulphates.

CONCENTRATION OF THE GOLD.

The gold in the oxidized ore seems to be somewhat concentrated, so as to be richer in some places than the average sulphide ore and poorer in others. This concentration does not appear to be important. The ferrous sulphate derived from the decomposing pyrite may have had some part in the process, for this salt is a very effective precipitant of gold in solution.

It has already been noted that the ore on oxidation becomes less coherent. This change is undoubtedly caused by a decrease in bulk, due to the leaching out of the more soluble portions. The chief part remaining is the insoluble silica.

LOCUS OF MINERALIZATION.

CONTACT OF PORPHYRY AND LIMESTONE.

The locus of greatest mineralization in the gold ores is primarily at the lower contact of the thin sheet of porphyry next above the lowest, or Silver-ledge sheet, with the blue limestone. From the contact the mineralization extends downward into the limestone for a few feet without great change, and then falls off rapidly, so that the ore gives place irregularly to unaltered and barren limestone, which, however, nearly always carries a trace of gold. According to the local intensity of the alteration the width of the zone which has been mineralized sufficiently to be available as ore varies from 2 or 3 to 25 or 30 feet, and as a rule the ore is richest where the quantity is greatest.

Above the contact, alteration and mineralization of the porphyry take place very slowly. This rock is always a good deal decomposed, and is often in a partly pulverulent condition. If the country were not so dry much of it would form stiff clays like those which are so common in the mines at Leadville. This altered porphyry always contains a trace of gold, but is generally not rich enough to be classed as an ore. Where the alteration has been least, and the mineralized zone of limestone is narrowest, the ore stops abruptly at the contact with the porphyry, so that the roofs of the stopes are usually smooth and uniform. Where the mineralization has been greater the lower part of the porphyry may be sufficiently impregnated to be mined along with the richer ores below; but it is always of distinctly lower grade than the altered limestone. Occasionally the whole porphyry sheet, where it is not very thick, may be sufficiently mineralized to form a low-grade ore. Above the porphyry, in localities where the mineralization has been especially great, the limestone is sometimes altered for a short distance, the softened portions extending irregularly upward into the hard rock. The writer has not seen any place, however, where the limestone above the porphyry was mined as ore.

JOINT PLANES.

The limestone which constitutes the ore is not always, perhaps not usually, greatly altered. Much of it is fresh and hard, while the softer altered rock occupies limited areas. The mineralization follows the same channels here as the alteration, being greatest along whatever cracks or lines of weakness may be present. There are no systems of intersecting joints in the rocks, such as might be supposed to result from regional stress. The northeast vertical fractures are not like ordinary joints, since they are variable in their distribution, sometimes being absent and sometimes forming intensely sheeted zones. But on the beginning of alteration the slight shrinkage causes certain planes of weakness to develop, chiefly a horizontal plane more or less exactly parallel to the stratification, and vertical planes having various trends, so that the rock is divided into blocks, from whose periphery the mineralization penetrates inward. In some of the ore, so small is the amount thus considerably affected that only the corners and edges of the blocks are rounded, and much the larger part of the ore is comparatively barren limestone. The pulverulent matter in the crevices is generally of a greenish tinge, resulting from the presence of oxidized arsenic compounds; this carries most of the values. A couple of assays were made to prove this. Both were from the same locality, a short tunnel just south of the United States Mineral Monument, on the top of Marion Hill. Here the limestone below the contact with the altered porphyry is mainly of the fresh, hard variety, and is separated into blocks, often slightly rounded by decomposition. From the outside of several of these blocks the greenish, decomposed material was scraped, all harder rock being excluded. This assayed in gold 0.125 ounce to the ton and nothing in silver. Then the same blocks were broken open, and the hard, sometimes cherty limestone was taken, to the exclusion of the softer parts. This assayed a trace in gold and 0.38 ounce in silver.

VERTICAL FISSURES.

The vertical fissures, which form one of the most conspicuous features in the mines, have undoubtedly been instrumental in opening the rocks through which they pass to the mineralizing currents. They are generally northeast in trend, varying considerably, but still ordinarily keeping near the average of N. 20° E.; they are generally vertical, with sometimes a very steep dip to the northwest, the angle of which is rarely less than 80°. Sometimes the notable fractures are a little distance apart and are separated by massive limestone; sometimes they are crowded close together and form a sheeted zone. Along such zones the pulverized rock crumbles readily, and is easily carried away, leaving the open fissures which have been described. In the ore bed, owing to the alteration, the fractures are ordinarily lost sight of, but they appear in the hard limestone above and below.

Two cases in the Mercur mine have been described where such a sheeted zone has determined an irregularity in the ore body, in the shape of a vertical tongue of altered and mineralized limestone, extending downward from the main ore sheet. These vertical zones of ore have walls of hard limestone on both sides. They are ordinarily exposed only for the height of the tunnels by which they are cut, and no data as to their downward extension can be obtained. In one case, however, that near the end of the main Nimrod tunnel, in the Mercur mine, an upraise has followed the vein for a distance of 50 feet or more, but the rock at the top was reported as growing harder and as very little mineralized. The drift which follows the same vein laterally shows the mineralization to become less and finally almost to disappear. Commercially, therefore, it is unlikely that any of these vertical zones of mineralization will become important; it is not probable that they extend downward for any great distance, or are persistent in any direction. On the other hand, the presence of these smaller ore zones is a proof of the possibility that bodies of similar nature may become large and persistent enough to be of value, and this fact should be kept in view in mining.

The fact, however, that the mineralization has proceeded more actively along these fissures and sheeted zones than in the rest of the rock is one of considerable importance. The walls of many open fractures carry crusts of arsenic sulphide, the form in which the arsenic of all the ores was originally deposited. This arsenic extends downward farther into the rock than do the mercury and the gold, and characteristically follows the vertical sheeted zones. Its presence as a sulphide shows that the alteration along these zones has not been due to an action secondary to the mineralization of the chief ore sheet above, by which the mineral elements were leached downward into the rocks below, but was brought about at the time of the original mineralization.

Other facts indicate the general tendency of the ore to run parallel with these fractures. In the mines where ore has been taken out in any large quantity the thicker and richer portions show a constant tendency to run in a northeast direction, in the manner of northeast parallel ridges on the under surface of the sheet. The great ore body which is exposed in the workings of the Mercur mine, and of which enough has been taken out to show its shape, is several times as long as it is wide, and its longer axis runs northeast. Furthermore, if a line be drawn from the middle of the Mercur mine through the Golden Gate ore body, it will have a direction of about N. 22° E., and if this line is extended southwest it runs close to the Mattie No. 5, where a small find of ore has been claimed, and through the Sacramento tunnel, where there has been considerable mineralization, but from which no ore has as yet been shipped. A parallel line drawn from the top of Marion Hill would pass close to the Marion and the Geyser, from the

former of which a large quantity of ore has been shipped; and to the Protective Tariff and Brickyard tunnels, which show many of the characteristic features of the Gold ledge mineralization, but have not become ore producers. A belt 1,000 feet wide in its widest parts, following each of the two lines described, would include all of the localities where the assays made by the Survey indicate that gold is present in quantity exceeding one-tenth of an ounce to the ton. These localities, in the belt drawn through the Mercur, comprise the Sacramento tunnel, the Mercur, and the Golden Gate; the zone drawn through the Marion would include the Marion, the Geyser, the Protective Tariff, and the Brickyard.

CONCLUSION.

The existence of a body of gold ore in the Mercur district is believed to depend on the following conditions:

1. It must be at and just below the under contact of a sheet of porphyry with limestone, and this contact must be one that has not suffered profound Silver ledge mineralization. Thin sheets are most favorable, for they have been most thoroughly decomposed, and this decomposition seems to have been favorable to the mineralization. Since the lowest thin sheet has been mainly rendered proof against further alteration by the effects of the Silver ledge silicification, it is on the contact of the sheet next above that all the valuable ore bodies have thus far been discovered. While other bodies may be found on other contacts, it is along this sheet that the most ore will probably be found in the future, as it has been in the past.

2. The ore is by no means distributed all over this contact, but only along certain sheeted zones, which are characterized by narrow, straight, open fractures. These zones are nearly vertical and have a general northeast trend, and where they intersect the lower contact of porphyry and limestone above described the ore bodies may be formed.

3. While the mineralization is characteristically greater along the whole extent of these zones than in the rest of the rock, it is only in certain portions that it becomes great enough to form an ore. The ore bodies, therefore, have probably in general a long northeast, with a considerably shorter northwest, axis, while the vertical dimension is comparatively small, rarely exceeding 30 feet.

AGE OF MINERALIZATION.

There is evidence that the mineralization of the gold ores occurred at a period later than the mineralization of the Silver ledge and the formation of the calcite veins which are so abundant in all the rocks. Some of the smaller of these veins may have been deposited later than the rest, contemporaneously with or even subsequently to the period of mineralization in the gold horizon, as various rather rare phenomena indicate; but nearly all were probably formed in the closing stages of the mineralization of the Silver ledge, or very soon after.

AGE OF VERTICAL FISSURES.

It has been shown that the vertical fissures existed before the advent of the gold, and were apparently the chief channels for this mineralization. That these fissures were formed after the mineralization of the Silver ledge is indicated in various ways. In many places in the mine workings they are seen cutting the older calcite veins, whose age is very nearly or quite that of the Silver ledge. On the side of Marion Hill and in Marion Gulch are many slight faults with a general northeast trend; near the mouth of the gulch most of the fault fractures have been completely healed by crystalline calcite. These, therefore, appear to belong to the older fracture system, corresponding to the calcite veins in the Silver ledge. On the hillside, however, are parallel fissures of the later open type, which cut the calcite veins. Along these later fractures, too, there has been some faulting, as one or two exposed sections show. In one place (see fig. 46) there is exposed a vertical sheeted and brecciated zone, over a foot wide and trending N. 40° E; the brecciated material is somewhat decomposed and loose, there being no

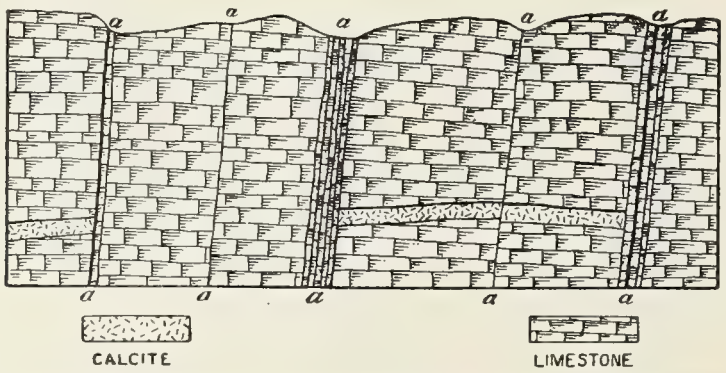


FIG. 46.—Open fissures in cliff on Marion Hill. *a*, *a*, unfilled fissures.

cement between the fragments. On the northwest side of the fractured zone there are many calcite veins in the hard limestone, mainly parallel with the stratification. One is nearly a foot wide. On the southeast side, however, there is not a single vein. The breccia contains many fragments of calcite, derived from the veins on the northwest side, showing that there has been some faulting accompanying the fracturing. As in most of the smaller faults in this vicinity, the upthrow is to the northwest, here about 20 feet.

In the Silver ledge proper the phenomena point to the same conclusions. The silicified and mineralized rock is traversed by large, vertical, open fractures, which have been described in the Silver Cloud workings and elsewhere. These fractures cut through the calcite veins and geodes and the altered limestone; their walls are generally bare, with only scanty beginnings of healing by calcite. In the case of the Marion gold mine and the old Carrie Steele silver mine, one of which is almost directly above the other, the same set of fissures run through both. In the gold ores above they are not usually characterized by

open spaces, but by slight faults, along which the ore has formed in such a way as to indicate that the mineralization has been subsequent to the fracturing. When these same fractures are encountered in the Silver ledge below, they are open, with hard bare walls, as if the fracturing were recent. The ore does not follow along these courses, and apparently has no connection with them. These facts all go to show that the mineralization of the gold horizon took place at a time distinctly subsequent to the formation of the silver ores.

EVIDENCE OF PRIMARY MINERALIZATION IN THE GOLD HORIZON.

Since the mineralization of the Silver ledge preceded that of the gold ores, we might expect to find, in places, traces of the primary mineralization on the horizon of the gold ores, for, according to the theory of the formation of the Silver ledge, the gold-ore horizon is one where some such action should have taken place, although in much less degree than along the sheet below. As a matter of fact, frequent phenomena were observed which apparently should be referred to this earlier mineralization. The cherty portion of the ore in the Gold ledge, where it has been least broken up and decomposed, is exactly like the characteristic rock of the Silver ledge. It will be remembered that this broken and cherty zone occurs, in the mine workings, always directly beneath the altered porphyry, and never extends far downward, nor is it found at a lower horizon. Where the limestone has been altered to ore below this zone, as it very commonly is, or where the chert is lacking, the rock is softened and becomes more friable; and since this softening is characteristic of the gold ores, it is evident that the hardening or silicification could not have been brought about by the same forces. Other things show that the chert was present before the introduction of the gold. One is its presence in brecciated condition in the ore, with loose, disintegrated material between, which contains most of the gold. This indicates a movement since the formation of the chert and before the mineralization, and this movement was undoubtedly contemporaneous with the vertical fracturing.

Another evidence that the chert was present prior to the mineralization is that it contains scarcely any gold, hardly more than a trace, even when occurring in the midst of the gold ores. This fact has been verified by various assays made by Mr. Hills.[1] In this connection an experiment previously described on ores on Marion Hill should be recalled. The ore under consideration is chiefly in hard, sometimes cherty limestone, which is separated into blocks by narrow zones of decomposed and pulverulent material. This lies under a belt of broken chert which in turn is below altered porphyry. From the outside of the blocks of hard limestone the greenish, pulverulent stuff was scraped, excluding the harder portions. This assayed nothing in silver, but in gold 0.125 ounce to the ton. Then from the same blocks a sample

[1] Op. cit., p. 9.

consisting only of the hard unaltered material was taken, which gave 0.38 ounce in silver and only a trace of gold. Since even traces of silver are practically absent in the gold ores, we must admit that the silver found in the hard limestone in the second assay must have been introduced by some earlier mineralization. The scarcity of silver in the chert at other localities in the gold ore is rather singular, but is undoubtedly to be explained by the ready solubility of the silver chloride. Where the rock has, as in these places, been profoundly fractured and exposed to the altering agents of the second mineralizing period, as well as to subsequent oxidizing forces, it is no great wonder that all of the silver has ordinarily been leached out.

Several other phenomena distinctly characteristic of the Silver ledge accompany the chert in the gold ores. One is the occurrence of the mineral Chinese talc, or impure jarosite. This is probably the product of the alteration of porphyry by waters containing soluble sulphates, which may have been derived from the oxidation of original sulphides. Such alteration may have had, therefore, no necessary connection with any distinct period of mineralization. In the case of the Silver ledge, indeed, it is believed to have formed at a period somewhat later than the mineralization, along with the alteration of the porphyry. In the case of the gold ores, however, the evidence goes to show that the decomposition was mainly accomplished before the characteristic mineralization took place, so that the formation of the Chinese talc was also probably prior to this mineralization. Since it is in its nature, habit, and association indistinguishable from the Chinese talc of the Silver ledge, a similar and in a general way contemporaneous origin may be supposed for both.

Barite has been observed in the gold ores only in the cherty rock, which is supposed to be due to the primary mineralization. In portions of the ore which are only softened limestone, with very little or no cherty material, it does not appear. In the chert the formation of the barite veins at the time of the primary mineralization is indicated by various phenomena. The habit of the veins is identical with that of the Silver ledge barite, since they are not characteristically persistent, but ramify in all directions, or penetrate the rock in a confused and intricate manner which can hardly be described or figured. As in the Silver ledge, the general tendency of the veins is rather to be parallel to the stratification of the limestone than otherwise, although some are vertical. In the Silver ledge, moreover, the barite is generally fresh, whereas in most places in the gold ore it is considerably decomposed, so that it crumbles readily on touching. Since this alteration is shared by the chert and altered limestone near it, it must have taken place before or at the time of the gold mineralization. The only change of importance which appears to have occurred since this is the oxidation, which is not capable of having produced all this decomposition. It follows

from this that the barite was probably in the rocks at a time previous to the secondary mineralization, and from its resemblance to the barite, which is known to have been formed at the time of the primary mineralization, as well as from its association, it may be supposed to have originated at the same time as the silver ores.

To determine as nearly as possible what was the relative content of gold originally present in the barite, a set of assays were made from material obtained in the Mercur tunnel, about 150 feet from the mouth. Here the veins are very large, some of them being nearly a foot wide in places. For this reason portions are comparatively fresh, while that on the outside of the veins is decomposed. There are left in the veins many cavities, into which the crystals of barite project, and from the barite forming the walls of these cavities the first sample was taken. This assayed 0.16 ounce in gold to the ton. Next, the freshest barite that could be obtained was taken, showing only traces of disintegration, and adjacent neither to the walls of the vein nor to the cavities. This assayed 0.025 ounce in gold. Next, a sample was taken from the altered limestone adjacent to the veins, from which all barite was excluded. This assayed 1.02 ounce in gold. At a little distance from the place where these three samples were taken the limestone contains small ramifying veins of barite. Both lime and barite are crumbling, and carry cinnabar. A sample of this barite was taken, from which, however, the pulverulent altered lime could not well be separated; indeed, it is probable that it formed the larger part. This assayed 2.42 ounces in gold. The result of these assays shows that the barite in its freshest condition in the gold ores carries only traces of the metal, thus furnishing a further point of resemblance to the barite of the Silver ledge; but where it has become decomposed and crumbling, as in small veins or on the outside of large ones, it has been mineralized with the limestone. The amount of mineralization, however, seems to be somewhat less in the barite than in the limestone.

PRIMARY AND SECONDARY MINERALIZATION IN THE SAME LOCALITY.

The characteristics of the Silver ledge on the southwest side of Mercur Hill have been already described (see p. 383). Here the silicified zone, which is about 10 or 15 feet thick, forms a prominent outcrop by reason of its hardness. Below this the limestone is hard and blue, showing no alteration even under the microscope, but appearing as a pure, uncrystallized limestone, apparently little different, except for consolidation, from the slimy form in which it was originally deposited. Above the Silver ledge comes from 15 to 25 feet of porphyry, considerably altered, although still quite hard in some places. Above the porphyry comes the blue limestone again, slightly hardened and crystallized along the contact, but not approaching the usual alteration of the Silver ledge. In the locality where the open cuts are the largest the porphyry is more decomposed than usual, being shrunken and traversed by curved and often concentric brown and yellow bands. It is thus in the

exact condition of the altered porphyry roof described in the gold mines. The Silver ledge below this is of typical appearance, although it shows a tendency to crumble at the top, and thus forms a somewhat gradual transition. At the exact contact the condition is identical with that of the broken and cherty parts of the gold ores in the Mercur mine. The primary mineralization seems to have been considerable here, for the silicification is very complete, barite veins are abundant, and the larger open cuts indicate a greater extraction of silver ore than anywhere else in the immediate vicinity.

From the altered porphyry samples were taken for assay. One test showed a content of gold in the ratio of 0.03 ounce to the ton, no trial being made for silver; another gave 0.018 ounce of gold and 0.6 ounce of silver. Although these amounts of gold are very small, yet they are as much as is often given by the altered porphyry roof in the mines, even in the ore bodies. In this case, however, the limestone below the porphyry, which at the main gold horizon forms the ore, was entirely silicified and mineralized at the time of the primary mineralization, and so was rendered insusceptible to much further change. Here, therefore, is a place where the two processes of mineralization have successively acted. The horizon, being that of the lowest porphyry sheet, is that usually characterized by the effects of the primary mineralization. In this case, however, the mineralization was not intense enough to harden the upper part of the porphyry above, which therefore softened and decomposed. Becoming thus a less permeable layer, it offered a local resistance to the ascending mineralizing agents of the later period, and hence was slightly impregnated with gold.

Near the Brickyard tunnel a rock analogous to the Silver ledge also shows evidence of the later mineralization. This is not the typical Silver ledge rock, for it is only slightly silicified; its position on the contact of the Gold ledge porphyry accounts for this. It is about 3 feet thick, and is like those portions of the Silver ledge along the contact of the lower sheet where the alteration has been slight. This rock gave no silver on assay, but 0.12 ounce in gold.

These facts suggest a modification of the general idea of the distinctness of the Gold and Silver ledges, which should be noted. While in general this distinctness holds true, it is possible that there may be places where ore will be found carrying a considerable quantity of both silver and gold; and bodies of gold ore may have been formed in places on the lower contact of the lowest porphyry sheet.

NATURE OF MINERALIZATION.

ALTERATION OF GOLD LEDGE PORPHYRY.

Although much if not most of the alteration which both the porphyry and the limestone of the gold horizon have undergone was probably accomplished prior to the period of the later mineralization, yet it connects itself with this process when the causes of the mineralization are

considered; for doubtless the altered condition of the rocks exercised a selective influence on the deposition of the ores.

A specimen of fresh porphyry from the vicinity of Eagle Hill shows under the microscope a finely microcrystalline ground-mass, in places made up of very small spherulites, which occasionally grade into a micropegmatitic intergrowth of quartz and feldspar. Lath-shaped microlites of feldspar are very common, but the main part of the ground-mass is not coarse enough to enable one to distinguish the component minerals. Phenocrysts are rare, but are fresh when found. They consist, so far as observed, of quartz, biotite, and orthoclase feldspar. The quartz is in crystals or irregular grains which show corrosion by the magma previous to the consolidation of the rock. The feldspar has crystal outlines, often rounded by corrosion, and shows no decomposition. The biotite is dark colored and strongly pleochroic. Along its cleavage cracks some of the iron has separated out as oxide.

Another specimen shows the beginnings of alteration. No change can be seen in the hand specimen, but under the microscope the ground-mass presents a yellowish tinge and a slight opacity in ordinary light. Around the edges of the spherulites, and in irregular patches throughout the ground-mass in general, there is an alteration which seems to result mainly in kaolin, while a less noticeable change produces occasional longitudinal flakes of muscovite. Next, the rock becomes finely porous, so that it adheres to the tongue; and it has a strong clayey odor. The phenocrysts are no longer distinguishable, and the iron of the biotite is gathered into scattered nodules of hydrous iron oxide, which gives to the hand specimen a brownish color. Often the oxide is concentrated into irregular wavy bands in the gray rock, such as are shown in fig. 47. The ground-mass is reduced to a very fine mixture, probably of silica and kaolin, which is sprinkled with muscovite. This is the typical state of the altered porphyries, both in the vicinity of the ore deposits and at a distance from them. At this stage the rock is generally soft and sometimes pulverulent. There seems to be a secondary action of a constructive nature, however, by which the grains of silica in the altered mass tend to grow continually larger, at the expense, apparently, of the kaolinic ingredients, and undoubtedly in part by the deposition of silica brought from outside by percolating waters. This process has generally had very small, although noticeable, effects in the porphyry of the gold ores; in that of the Silver ledge, however, where the silica is very abundant in the contiguous rocks, it appears to have caused in places a considerable transformation.

The evidence goes to show that the alteration of the Gold ledge porphyry was accomplished mainly after the deposition of the silver ores and before the deposition of the gold. The silver ores seem to have been deposited immediately after the intrusion of the porphyry, before

any oxidizing agents could have had opportunity to act. The conditions under which they were deposited, moreover, were evidently such as to preclude the idea of the operation of such oxidizing agents as were evidently active in the alteration, until after the lapse of a considerable period of time. On the other hand, where there has been no mineralization the alteration is exactly like that in the gold ores, thus showing that the mineralizing agents had no important part in the process. Since this is the case, not only in the oxidized ores but in the sulphide ores as well, the alteration since the mineralization must also have been

FIG. 47.—Concentration banding in slightly altered porphyry. Natural size.

very insignificant, for the altering agents could not well have acted without affecting the sulphides, particularly that of arsenic, whereas in much of the rock microscopic study has shown that no oxidation has taken place. The structure of the ores, both in the field and under the microscope, points to the same conclusion—that the porphyry had very nearly reached its present state of decomposition before the minerals were deposited.

ALTERATION OF LIMESTONE.

The fresh limestone is exceedingly fine-grained, the individual grains being often so small as not to be distinguishable under the microscope. It is slightly darkened by the presence of organic matter, which gives it in the hand specimen its dark gray-blue color, but it is, notwithstanding, a very pure lime carbonate without dolomitization or any appreciable amount of silica. Scattered thickly throughout its mass are ordinarily many varied shapes of clearer and coarser calcite or aragonite, which are the sections of tiny marine fossils.

So far as observed, the process of alteration of the limestone seems to have been a gradual dissolution of the lime, with or without attendant replacement by cryptocrystalline silica. Sometimes this process has been entirely completed, so that the limestone is converted into a typical chert, dark-gray in color, and called "black quartz" by the miners. Microscopically it has the cherty structure, and is composed of silica varying from very finely cryptocrystalline to finely phenocrystalline, with often small but abundant cavities and veinlets partly or wholly filled with crystalline quartz. In other cases there remain in the chert small, irregular patches of calcite, which are probably residuary. Sometimes these patches are crystallized into rhombohedra. From a limestone partly replaced by silica the remaining calcite has very often been dissolved out. If silica has already replaced the greater part of the rock, there results from this leaching a very porous chert, full of small, irregular cavities; if the lime is still in excess, the silica is very often not in sufficient quantity to preserve the shape of the rock after its withdrawal. The rock therefore crumbles and becomes reduced to the light-gray pulverulent altered limestones of the oxidized gold ores and to the soft "black shale" of the sulphide ores, where the grains of quartz are to a certain extent cemented by the later minerals which accompanied the gold.

Most of the chert in the gold ores was probably formed before the introduction of the gold and the accompanying minerals, and probably at the time of the primary mineralization of the Silver ledge. This is shown by the similarity of this chert to that of the Silver ledge, and by the fact that it incloses some of the same most conspicuous minerals, such as barite and Chinese talc. The ores of the Gold ledge, moreover, were evidently not deposited at the same time as the chert, for where this chert is dense it contains only traces of gold; where it is porous the characteristic minerals of the later mineralization are found in its pores, and where the chert has been broken by a movement subsequent to its formation, the finer material between the larger fragments of the breccia has been chiefly impregnated.

REALGAR.

The most abundant and conspicuous mineral which has resulted from the later mineralization is the sulphide of arsenic. No one of the other minerals of the Gold ledge is present in such quantity and condition as to throw any light on the conditions of deposition. The gold itself has not been seen in the ores, even under the microscope; the form of the unaltered mercury in the sulphide ores has yet to be determined; pyrite is present in only small quantities, and the barite was probably in the rock before the later mineralization. But the sulphide of arsenic is nearly always distributed abundantly throughout the unaltered ores, and can be readily observed.

Under the microscope realgar is a very striking mineral, on account of its high single refraction and its rich reddish-brown color. It is translucent, and has a marked pleochroism, varying from golden-yellow, through greenish-yellow, to golden-brown. Under crossed nicols it shows a deep golden-brown. It alters on oxidation to a brilliant yellow mineral, which analyses show to be probably scorodite, a hydrous ferric arsenate. This is the greenish-yellow pulverulent mineral which is seen in hand specimens of all the oxidized ores.

In a section from a cherty portion of the ore in the Golden Gate mine the realgar occurs in irregular grains scattered through a mass of fine cryptocrystalline silica. The silica is very full of a very fine, dust-like, dark material, which gives the dark color to the rock. This material is arranged in imperfect lines or zones, forming a rude network; some of the larger bunches of this can be distinguished as very small, irregular grains of pyrite. There is a single large grain of barite, with ragged boundaries, but the barite and the realgar are not associated, and there is no evidence of their relative age. There are also sparsely disseminated, small grains of an opaque, grayish-black mineral, with dull metallic luster, which seems to have crystallized with the realgar. This resembles a mineral found in small quantities associated with the earthy cinnabar in the oxidized ores, of which enough could not be obtained for determination. It seems probable that it may be the original form of the mercury, since cinnabar is wanting in the sulphide ores except in very small specks, which are apparently the result of incipient oxidation. There is no crystalline quartz or calcite in the section, or other gangue for the realgar.

In another section of a Golden Gate ore very rich in realgar, which is not cherty but goes by the name of "black shale ore," the rock seems to be an altered porphyry, similar in every particular to the other altered porphyries near by. Much of the section is taken up by large grains of realgar, with irregular outlines. Realgar also forms a fine network through portions of the uncolored mass which represent the original rock. There is no gangue of silica, calcite, or barite.

CALCITE.

Throughout most of the ores calcite is entirely absent, and when present is in small quantities, which are probably residual from the limestone. In a few cases crystalline calcite is associated with the characteristic sulphides of the later mineralization, but this generally occurs outside of the body of the ores, and marks an inconspicuous process which is probably distinct from that which has formed the main part of the ores. Not even in a restricted sense can calcite be considered a gangue of the sulphides of the gold horizon.

BARITE.

Barite is found scattered through the gold ore in large veins, as already described, and also in small grains which are visible only under the microscope. These grains have usually irregular outlines, but often crystal boundaries. They may consist of a single individual, or may be an aggregate of minor grains. They are surrounded by chert and have the appearance of having crystallized at the same time with the silica. Whenever the minerals of the later mineralization are present there is apparently no close connection between them and the barite.

QUARTZ.

Megascopic and microscopic examination shows that crystalline quartz, like calcite, is generally absent from the gold ores. In only one of the sections examined was any quartz observed other than the fine-grained variety which makes up the chert, and which is evidently of an earlier origin than the mineralization. This section is from the side of an open fracture plane in the Marion mine, and shows numerous very small crystals of quartz surrounded by the chert of the completely silicified limestone, in which the outlines of fossils are still discernible. It is probable that in this case the crystals formed before the mineralization. In several sections from the similar ores of Sunshine, crystalline quartz was also found, generally in very small individuals, as above. In one section a very large crystal was found. This was much fractured and broken, with irregular corroded outlines. The arsenic sulphides penetrated the fractures and filled the spaces between the broken fragments, showing that they were undoubtedly introduced after the formation of the quartz. A single small megascopic crystal of quartz was found in the ores of the Mercur mine, but there is no evidence that it formed at the time of the mineralization.

PYRITE.

The analysis of the sulphide ore from the Golden Gate mine shows 6.60 per cent of iron sulphide. So far as has been observed under the microscope, most of this seems to be in very small, dust-like particles,

which grade into larger, generally irregular grains, large enough to be recognized. There is no connection between the pyrite and the realgar, and the distribution of the former mineral and its general habit support the belief that the iron was not introduced into the rock at the time of mineralization, but existed previously in the form of disseminated iron oxides, which in turn were chiefly derived from the altered biotite and other iron-bearing silicates of the porphyry. This oxide was probably transformed into the sulphide at the time of the later mineralization.

IMPREGNATION OF THE LIMESTONE.

It is by the characteristics of the realgar that the nature of the mineralization must be judged, since the minerals which accompany it are not abundant enough to admit of careful observation. So far as the observation of the realgar goes, there is no positive evidence that any of it was deposited by a process of molecular substitution for the silica or the calcite. On the other hand, it is often present in grains whose form suggests the filling of preexisting cavities, and it is known that such irregular cavities existed in both the altered porphyry and the limestone, but particularly in the latter.

A section from the Marion mine shows the process by which the altered limestone becomes extremely porous. It is taken from a portion of the rock along a fracture plane, where the silicifying solutions seem to have acted more potently than in the rest of the rock. Near the walls of the fracture the rock has been in large part altered to a typical dark-gray chert; somewhat farther away there has apparently been a complete silicification, but the rock has a light-gray color and the characteristic texture of limestone. Still farther away it has become almost pulverulent, from partial silicification and the leaching out of the calcite which still formed the larger part of the bulk. Here the outlines of Bryozoa can be seen, like those in the unaltered rock. The section is cut from the hard, apparently totally silicified rock, which retains the texture of limestone. Under the microscope it is found to be mainly a fine-grained chert, which still, however, contains small grains of cloudy calcite scattered through it, sometimes irregularly and sometimes segregated into rhombohedra, and plainly residuary. In some parts of the section this calcite has been dissolved out, and the chert is left very full of small, open cavities of irregular shape. It is probable that in cavities formed in this and other ways most of the minerals of the later mineralization were deposited. It may be that some were also deposited by a process of actual substitution, the sulphides replacing the residual lime, and also, possibly, to a small extent the silica, but it is probable that the general process was rather one of impregnation than of replacement.

PROCESS OF MINERALIZATION.

ORIGINAL DEPOSITION AS SULPHIDES.

All of the ores of the gold horizon were originally deposited in the condition that we find them in the unaltered parts of the sulphide ore, as seen in the Golden Gate mine. All stages of the transition from the sulphides to the oxidized ores can be seen in almost every locality where the ores are extensively exposed.

ASCENDING TENDENCY OF AGENTS.

The distribution of the ores with reference to the porphyry sheet, which evidently determined their deposition, shows that the agents which brought about the mineralization were ascending. The locus of greatest mineralization is typically at the lower contact of the porphyry with the limestone, and from this point extends downward into the limestone a few feet, and to a less degree upward into the altered porphyry. It thus forms a continuous bed-like deposit on the lower side of the porphyry, while on the upper contact the rocks are not mineralized, except in places where the mineralization has extended upward through the porphyry and includes a small portion of the limestone immediately above. So slight is the thickness of the porphyry that it is not possible that the ores could have been derived from it by leaching and so carried downward into the limestone. The only explanation is that the mineralizing agents rose from below till they met the sheet of altered porphyry, when they spread out along the under contact and so produced the mineralization. The channels along which they rose were most likely the open vertical fissures. Where these are thickest the mineralization is richer in the normal ore horizon and extends downward farther into the limestone.

NATURE OF THE AGENTS.

In comparing the primary or Silver ledge mineralization with the later or Gold ledge mineralization, it is seen that ores remarkably alike in geological position differ widely in their chemical and physical phenomena. Both have the same form, being bed-like deposits along the lower contact of a thin sheet of porphyry; one lies directly below the other at a distance of only about 100 feet; and in both cases the porphyry and the limestone with which they are associated are the same in age, chemical composition, and structure. Since, therefore, the rocks in which the ores are found can not furnish any explanation of the difference, it must be that it arises from the nature of the agents which accomplished the mineralization. In the Silver ledge the agents were heated waters, like those which have brought about the formation of many other ore deposits; but they were probably derived from the lava itself at the time of consolidation, instead of being surface waters

which, having sunk into the ground, came in contact with the heated igneous rock and rose again toward the surface. This hot-spring action is undoubtedly responsible for the existence of a large number of ore deposits, but is not applicable to the silver ores of Mercur. In the gold ores the phenomena are so totally different that the same explanation can not possibly be applied. Either the agents were not heated waters, or they contained in solution entirely different elements derived from other sources. The actual phenomena of the gold ores make the first supposition the more probable of the two.

There is no evidence in the gold ores of any such extensive dissolving and reprecipitation of the elements of the rock as would naturally accompany the passage of a large body of heated water, and as has actually occurred at the horizon of the Silver ledge. The walls of the fissures or sheeted zones, which have been the chief channels for the mineralizing agents, are perfectly straight, and where a fissure has been widened it is by the crumbling of an especially intensely sheeted zone of the rock. There has been no corrosion of the limestone on the sides of these fissures, resulting in the formation of irregular cavities, and no deposition of recrystallized calcite along their walls. In the main ore horizon the same thing is seen. There appears to have been no gangue of calcite or quartz, which accompanied the arsenic and other minerals, although even in the unoxidized ore most of the rock is soft and the pores and interstices are only imperfectly filled with the sulphides. If silica or quartz had been present in the solution, it would have had abundant opportunity to crystallize out in the imperfectly filled interstices, and have afforded a gangue for the realgar, at the same time cementing the rock and making it solid and firm. The mineralizers, therefore, contained neither silica nor lime, nor agents capable of taking these elements into solution.

Arsenic, mercury, and gold are the only elements which it is certain were introduced into the rocks at the time of the later mineralization. In accordance with the derivation of the pyrite which has been suggested, there was probably also free sulphureted hydrogen. The arsenic was deposited as sulphide; the original form of the mercury is not known; and it is not certain what was the form of the gold, although the presence of tellurium in the analyses suggests a telluride. The selective association of these three rare elements, with the exclusion of nearly all of the commoner ones, certainly indicates unusual conditions of deposition. Particularly noticeable in the analyses is the absence of even a trace of lead, copper, antimony, silver, zinc, manganese, nickel, and cobalt, while the iron was probably in the rock before the mineralization. In most metalliferous spring waters some or all of these metals are present. The deposits at Steamboat Springs, in Nevada, which are now being actually formed by hot springs, and which resemble the Mercur gold ores in containing sulphides of arsenic and mercury, together with gold, contain also sulphide of antimony,

ferric hydrate, lead sulphide, copper sulphide, and silver, together with traces of zinc, manganese, cobalt, and nickel.[1]

The peculiar phenomena of the gold ores and their difference from the ores of the Silver ledge are explained by the supposition that the mineralizing agents were rather in a gaseous than a liquid condition, or that the ores were pneumatogenic rather than hydatogenic. Mercury and arsenic are the most volatile of metals, metallic mercury volatilizing at ordinary temperatures and metallic arsenic at about 130° C. Schrauf has shown that the sulphide of mercury volatilizes in laboratory experiments at about 237° C., and probably at far lower temperatures in nature; while the sulphide of arsenic is also easily volatile, the process by which most of it is prepared artificially depending on this property. Concerning the volatility of the telluride of gold, not much appears to have been determined; but from the loss of gold from telluride ores when treated by any process which includes heating, it appears to be easily volatile under favorable conditions. These metals would be the first to pass into the state of vapor and the last to be deposited. In this way they might be separated from solutions containing chiefly the more common metals, and they might continue in the gaseous condition under far lower temperatures than indicated above if accompanied by gases capable of absorbing them.

HYDATOGENIC CINNABAR AND REALGAR.

Opposed to the ordinary occurrence of cinnabar and realgar in this region, where the sulphides are apparently mainly pneumatogenic, are certain comparatively rare occurrences where the phenomena are different, and plainly indicate that the minerals were deposited from circulating waters.

Only a single specimen of cinnabar was of this sort. This was taken from a fracture in the Marion mine, and is of the dark-red crystalline variety. There is a plentiful gangue of fine-grained calcite, which fills most of the fracture. In the middle of the specimen a narrow cavity is still left unfilled, and on the sides of this cavity calcite forms small, perfect crystals. Intergrown with the calcite is the crystalline cinnabar, sometimes entirely inclosed in a crystal of calcite, and sometimes coating the outside. Contemporaneous deposition of calcite and cinnabar is thus shown. All other cinnabar found in this district was of the vermilion-colored, earthy kind.

Cases of realgar having this association are more common. At different places, generally outside of the rock which is sufficiently mineralized to be classed as an ore, small veins of granular calcite contain isolated grains of realgar. Judging both from field and microscopical evidence, these grains have crystallized simultaneously with the calcite. But the limestone in which the veins usually occur appears quite

[1] G. F. Becker, Mon. U. S. Geol. Survey, Vol. XIII, 1888, p. 343.

fresh, with even its most delicate organic structures uneffaced by any alteration.

These examples of hydatogenic formation indicate a process which is distinct from that which has produced the ores in general, and which has operated only in a feeble manner. It has the appearance of being one of the most recent operations connected with the ores, and is probably to be referred to a later period than the general mineralization. Indeed, the conditions of the present day as they exist in the sulphide ores are probably sufficient to account for these occurrences. Ordinary surface waters percolating through the rock are capable of taking into solution lime from the interstices of the rock and of precipitating it along the fissures as regenerated calcite, and Becker[1] mentions a case where cinnabar has formed on the walls of a drift since its opening. The little cinnabar and realgar that is evidently hydatogenic, therefore, may be derived from the original pneumatogenic sulphides by rearrangement since their deposition, due to percolating waters. It is also very possible that the waters which have produced this result were connected with the original mineralization, and were present in small quantities at the close of that process.

THEORY OF GENESIS.

The part played by gaseous agents in the formation of ores has been but little regarded of late. Considered as a gold deposit, that of Mercur is certainly unusual, for in most deposits the gold has been undoubtedly precipitated from circulating waters; in the typical gold-quartz ore this is beyond a question. Suess,[2] however, considers that vapors may have formed gold deposits, as well as those of the other metals, and it seems probable that the conditions governing the deposition of the telluride of gold are different from those which bring about the concentration of the native metal.

Considered as a mercury deposit, the theories advanced come more in line with previous observation. On account of the extraordinarily easy volatility of mercury, its deposition from a gaseous condition has long been a favorite explanation of its occurrence, and undoubtedly has been often applied to cases where the deposition was actually from waters. Becker has shown that the cinnabar deposits of California, which were long considered as having been partly at least deposited from vapors, are probably derived from ascending heated waters. On the other hand, Professor Schrauf[3] considers that the cinnabar of Idria, in Austria, was deposited mainly from moist vapors. He distinguishes two distinct methods of occurrence, like those which have been noted for the gold ores of Mercur—a primary pneumatogenic deposition, and a later hydatogenic deposition, the former being distinguished by the

[1] Monograph XIII, p. 307.
[2] Die Zukunft des Goldes, Wien, 1877, p. 98.
[3] Jahrbuch k. k. geol. Reichsanstalt, Vol. XLI, 1892, p. 390.

absence of gangue minerals, such as regenerated calcite, and the latter by their presence.

Arsenic is a very common mineral in the vicinity of volcanoes, where it is deposited from the vapors of the fumaroles. Daubrée[1] classes arsenic among the substances characteristic of stanniferous deposits, which are generally considered as of gaseous origin; the other characteristic substances are silica, fluorine, boron, and phosphorus.

A general theory for the deposition of these gold ores may then be formulated as follows:

Subsequent to the introduction of the porphyry and the formation of the silver ores, a comparatively local disturbance brought about the formation of a set of nearly vertical northeast fissures or fractured zones. These fissures established a communication with a body of uncooled igneous rock at an uncertain depth below and afforded a vent for moist volcanic vapors. The decomposition of the Gold ledge sheet of porphyry was already far advanced at the time of the formation of the fissures; these fissures, therefore, did not continue into the porphyry as open channels; the movement produced in the porphyry only a slight rearrangement of the individual grains. In the lowest sheet, however, that of the Silver ledge, the porphyry had become so indurated at the period of the primary mineralization that in only a few cases, in the vicinity of the principal mines, does it show any subsequent softening, due to oxidation; in this hard altered porphyry the fissures are as clean cut as in the limestone. The ascending vapors therefore found no impediment to their progress till they reached the second sheet, but this offered no open passages, and so interposed a blanket-like barrier to further upward motion. The limestone at the lower contact of the porphyry, however, had been partly silicified at the period of primary mineralization, and, in the succeeding period, had been rendered porous by the leaching out of a large part of the residual lime. Along this porous zone the vapors spread out, and, becoming cooled, deposited the gold and the associated minerals; they also penetrated to a small degree upward into the less permeable altered porphyry.

This theory does not dispense with water as a mineralizing agent; indeed, it is most probable that water in the form of steam has played a very important part. Dana remarks that in ordinary volcanic vapors water makes up 99 parts in every 100, and Scrope considered that it composed 999 parts in every 1,000. The solvent power of steam on the more volatile metals is undoubtedly much more powerful than that of even highly heated waters; and this may be held to account in part for the great difference between this and plainly hydatogenic deposits in the proportion of minerals introduced to the rearrangement of the country rock by the accompanying solutions.

[1] Géologie expérimentale, Paris, 1879, p. 30.

Fumarolic activity in eruptive rocks is not of slight duration, but often lasts, with little change, through long periods of time. Even at the surface the loss of heat from a lava is surprisingly slow. Scrope mentions the case of a bed of lava at Jorullo, in Mexico, which emitted vapors from fissures till nearly a hundred years after its eruption. When the eruptive rock is buried at even a very slight depth, the length of time that it retains its heat is enormous. Scrope[1] and Lyell[2] both cite the case of the fumaroles at Pozzuoli, near Naples, which were in the same condition in the time of Homer as at present; at the opening of the principal fumarole, Prof. É. de Chancourtois found cinnabar and realgar, which had been deposited from the jet of gases.[3] In Utah, Gilbert has noted[4] fumarolic activity still existing in a cinder cone of Tertiary age; and he judges that this action has been kept up steadily since the formation of the cone. "After most eruptions," says Scrope,[5] "a vast body of heated lava is likely to remain beneath the bottom of the crater, in which the process of solidification goes on slowly for an indefinite and often very long period, affording a continual source of aqueous vapor charged more or less with various mineral substances."

SUMMARY OF GOLD LEDGE GEOLOGY.

What is known as the Gold ledge is a mineralized zone which is developed in the lower part of the Mercur Basin, and mainly on Mercur and Marion hills. This zone is chiefly an altered limestone, and follows the under contact of a thin sheet of porphyry, which is itself so greatly altered as to be often hardly recognizable, and which is situated about 100 feet above the porphyry sheet that is characterized by the phenomena of the Silver ledge. The mineralization of the limestone along the contact of this upper porphyry is not continuous, but varies from nothing up to 15 or 20 feet. The lines of greatest mineralization seem to coincide in direction with a set of nearly vertical northeast fissures, so that the ore forms northeast-trending shoots or channels. The typical form of the ore body therefore has a long northeast axis, a considerably shorter horizontal axis at right angles to the first, and a very short vertical axis.

The ores are divided into two classes, which, however, were originally alike, the oxidized and the sulphide ores. The former are chiefly shown in the Mercur and the Marion mines, and are thus far the only productive ores, since the gold can be extracted from them by leaching with cyanide of potassium; the latter are best developed in the Golden Gate explorations, and can be leached only after roasting.

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[1] Volcanoes, London, 1872, p. 230.
[2] Principles of Geology, 1872, p. 603.
[3] Mon. U. S. Geol. Survey, Vol. XIII, 1888, p. 36.
[4] Mon. U. S. Geol. Survey, Vol. I, 1890, p. 334.
[5] Op. cit., p. 147.

In the sulphide zone the ores are soft and shale-like, and in the oxidized zone they become partly pulverulent, although in both there is much chert scattered throughout. This softened and altered limestone has a composition which is little like that of the original rock, being chiefly made up of silica of the cryptocrystalline variety. Crystalline quartz is rare. Besides the silica, the ores are characterized by the sulphides of arsenic, iron, and mercury; barite, calcite, gypsum, jarosite, and melanterite are not uncommon, and variscite and rhodochrosite have been found. Scorodite is a characteristic mineral of the oxidized ores, arising from the alteration of the realgar.

The amount of gold in the ores is never very great, rarely exceeding two or three ounces to the ton, and averaging much less. Silver is generally entirely absent. It is probable that the gold exists in the original sulphide ores, as telluride, and that on oxidation it has become free gold.

The mineralization of the Gold ledge probably took place at a distinctly later period than that of the Silver ledge, and the general nature of the phenomena indicates that the agents were gaseous rather than liquid; that they ascended along the open vertical fissures, probably from some uncooled body of igneous rock below, and impregnated the zone at the lower contact of the porphyry sheet, which was already altered and porous from the effects of the earlier Silver ledge mineralization, with arsenic, mercury, and gold.

THE PUBLIC LANDS AND THEIR WATER SUPPLY.

BY

FREDERICK HAYNES NEWELL.

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THE PUBLIC LANDS AND THEIR WATER SUPPLY.

By Frederick Haynes Newell.

INTRODUCTION.

Questions as to the best methods of utilization and disposal of the vacant public lands have been of great prominence ever since the birth of the Republic, and the inauguration of a wise and judicious system of land laws has been deemed one of the noteworthy achievements of the early part of the century. Many questions, however, are still far from being finally settled; for with the rapid changes incident to the growth of the nation, the settlement of the Mississippi Valley, and the construction of many transcontinental lines of communication leading to the highly cultivated and thickly populated lands of the Pacific Coast, new conditions have arisen to which former precedents and customs are no longer applicable.

While the well-watered lands stretching from the Ohio to the Missouri were open to settlement, the problems were mainly those of administration; but now that the humid lands are disposed of, and pioneers are pressing forward to every part of the vast interior region where water and not land is the first item of value, it becomes necessary to modify the treatment of the public lands and to introduce better methods. Such necessary improvements, or the introduction of systems leading to greater prosperity, must depend to a large extent upon the possession by the general public of broad yet accurate knowledge of the chief characteristics of the remaining public domain. This knowledge can be obtained only by a thorough scientific examination and an impartial statement of the facts as ascertained by disinterested observers.

There is still vacant and open to settlement within the boundaries of the United States (not including the Territory of Alaska) an area comprising nearly 630,000,000 acres, or one-third of the total extent of the country. This vacant land is not wholly unutilized, since a great proportion of it is of value for grazing purposes and sustains large herds of cattle and flocks of sheep. No rent or fee is paid by the owners of these herds and flocks, the range being free to all, and as a consequence the business of grazing has increased to such an extent that

the ranges are overstocked, and in places the extermination of valuable native grasses is threatened. The owners of these wandering cattle and sheep are often nonresident, have little or no interest in the permanent development and improvement of the country from which their wealth is drawn, and may even use their influence—strong through concentration in the hands of a few—toward the retardation of settlement and the building of homes.

Within the vast extent of vacant public lands there is also an unknown area—amounting to scores of millions of acres—of forests and wooded lands, whose products are of primary importance in the development of civilization at innumerable points. These forests and woodlands belonging to the nation have no protection; they are subject to depredation on every side, and, incomparably worse than this, to the ravages of fires kindled by careless or malicious persons.

The land laws of the United States provide for perhaps the best method of disposing of the fertile, well-watered prairies, plains, and slopes of the Mississippi Valley. There the results have been happy, and prosperity has followed the rapid acquisition of homesteads by thrifty and energetic settlers; but the conditions now are almost wholly changed. These broad acres, so well adapted to subdivision by the rectangular system, and which, when thus subdivided, have an almost equal value at every point, have now passed out of the possession of the National Government; and although an enormous area still remains—an area three times as great as the aggregate of the thirteen original States of the Union—it can not be expected that the continued application of methods and rules proper for the humid region will be followed by prosperity and the best results to the average settler. This has been pointed out again and again within the past decade, and was dwelt upon by Major Powell and his assistants in their notable report upon the arid region.[1] The needs pointed out by this report become more pressing as the small remaining area of humid lands is taken up and the vacant public lands are found to embrace only those of arid or semiarid character.

It is not, however, the intention in this paper to dwell upon the land system of the United States, nor to make suggestions as to its modification, but simply to point out the location of the public lands, to indicate in a general way their extent and position, and to lay before the public such facts as have been obtained concerning their broader physical characteristics, and especially their water supply. The latter is still a subject of investigation, and although considerable work relating to it has been done, in view of the enormous extent of country to be traversed it can hardly be said to be more than inaugurated. This discussion of the location and extent of the vacant public lands is intended to be by no means exhaustive, but is designed rather to serve as a guide in matters

[1] Report on the Lands of the Arid Region of the United States, with a More Detailed Account of the Lands of Utah, with Maps, by J. W. Powell, Washington, 1879.

pertaining to a thorough study of the possibilities of utilization of the resources of the national domain.

In what has been known as the organic law of the Geological Survey, approved March 3, 1879, it is provided that the officer in charge of the Survey shall have direction of the classification of the public lands. Such classification, however, will be possible only after an exhaustive study of the geography and geology of the country has been made and a thorough knowledge of the processes involved in the best utilization of the natural resources has been gained. This classification is therefore by no means so easy or simple as might be supposed, and at the same time it is an undertaking of great importance to the nation at large. To make a useful classification, to point out the possible value of millions upon millions of acres of wild and unsettled lands embracing every variety of topography, of climate, and of geological structure, is a stupendous task. The first requisite is a good map; next, a knowledge of the structure, rocks, and soils; and with these, some information regarding the most essential and yet the most fluctuating form of mineral wealth—the water supply. Through the broad conceptions and the indomitable persistence of the founders of the Geological Survey, the mapping and the study of the existing conditions have proceeded rapidly, and the public is now able to ascertain the facts regarding the physical conditions of large portions of the national domain. The work is well under way, but to comprehend its magnitude, when applied only to the unoccupied lands of the United States, it is necessary to have clearly in mind the location and character of these lands.

The need for a general map of the vacant areas was early recognized, but the numerous difficulties seemed to preclude such an undertaking. The attempt to ascertain what and where the public lands of the United States are is a matter of difficulty and expense, and considerable dissatisfaction has arisen from the uncertainties of the determinations already reached. Upon the books of the General Land Office is entered the status of each parcel of land which in any way has been reserved, filed upon, or disposed of; but these ledgers number thousands, and embrace almost innumerable entries in a state of suspension, awaiting rulings or decisions. It would require the services of a hundred experienced clerks for a number of months to abstract from these books and tabulate with any degree of accuracy the figures relating to vacant lands. Such a task, unless authorized by special act of Congress, could not be undertaken. A shorter method was, however, suggested, and through the special interest of Maj. J. W. Powell, then Director of the Geological Survey, a number of employees in this Bureau were detailed to rapidly examine the more important tract books and to check off upon a map of each State the larger groups of entries. The result was a graphic representation which is sufficiently accurate for the small generalized map (Pl. XXXV) herewith presented.

For a number of years the reports of the General Land Office have

contained estimates, by counties, of the vacant public land in each land-office district. Some of these estimates are prepared carefully and conscientiously, while others are not. In the following tables, showing the extent of the public lands, the figures published in the annual reports of the General Land Office have been used whenever inspection indicated that they had been carefully prepared. Where, however, it was evident that these figures were not complete, new computations were made, based upon the disposals of the public lands for the last thirty years. By this means it is believed that the figures herein presented have been made reasonably accurate.

LOCATION AND EXTENT OF PUBLIC LANDS.

The map, Pl. XXXV, made in the manner described, exhibits graphically the location and extent of the public lands of the United States. The red color indicates the lands formerly owned by the General Government which have been sold, granted, or disposed of in various ways to individuals, to States, and to corporations. The uncolored portion, consisting in the eastern part of small, inconspicuous dots, and in the western of large areas, designates the lands now belonging to the General Government and open to entry and settlement under the various land laws. The bands of cross-hatching extending across the western part of the country show the areas within which every alternate section has been given to railroad companies to aid in the construction of the transcontinental lines. The smaller similarly marked areas in Oregon indicate the grants for the construction of military wagon roads. Indian and forest reservations are also shown on the map, by green and orange, respectively.

The relative area of these various classes of public land, as compared with the whole of the land area of the United States, is shown by the following table and in the diagram, fig. 48, these figures being totals, the details of which are given later under various headings. The table gives these areas both in square miles and in acres, since it is sometimes convenient to use one and sometimes the other of these units. The areas are also expressed in percentages of the total land area of the United States, in order to show more clearly their relative magnitude.

Relative extent of the public domain.

	Square miles.	Acres.	Per cent.
Vacant public lands	980, 337	627, 415, 680	33. 01
Indian reservations	131, 689	84, 280, 960	4. 43
Forest reservations	30, 445	19, 484, 800	1. 03
Lands disposed of	1, 107, 044	708, 508, 160	37. 27
Area of older (19) States	458, 195	293, 244, 800	15. 43
Area of Texas	262, 290	167, 865, 600	8. 83
Total land area of United States	2, 970, 000	1, 900, 800, 000	100. 00

As shown by the above table, the vacant public lands comprise 980,337 square miles, or 627,415,680 acres, this being 33.01 per cent of the total area of the United States, exclusive of Alaska, or very nearly

one-third of its land surface. The character of this vacant land and its distribution according to States and Territories are discussed at some length in the following pages. A small proportion of this land will probably be claimed in the future by transcontinental-railway companies as part of the grants made to aid in the construction of their roads, or as indemnity for sections to which title can not be obtained. But this amount is relatively small. Of this vacant public land 26,822 square miles (p. 477), or 17,166,080 acres, are in the eastern part of the United States. This quantity is only nine-tenths of 1 per cent of the total area of the United States. The remainder of the vacant land, as previously stated, is in the West, and is mainly within the arid regions.

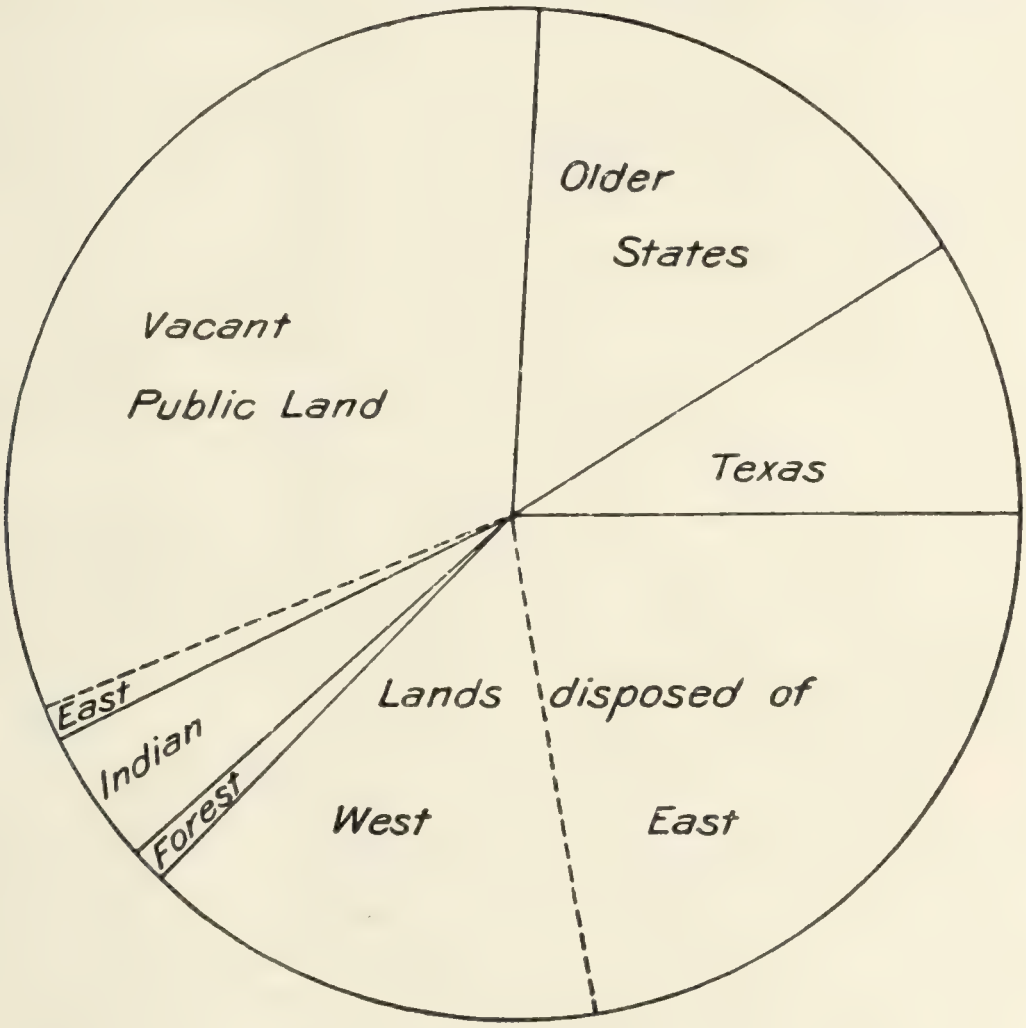


FIG. 48.—Diagram illustrating relative area of public land vacant.

Under the head of Indian reservations the table shows 131,689 square miles, or 4.43 per cent of the total area of the United States. Under this designation is included, however, the whole extent of the Indian Territory, and also the military reservations of the West, the latter amounting to 2,456 square miles. These figures are discussed more in detail on pages 490–492. Each year portions of tracts of land held as Indian reservations are allotted in severalty and the balance thrown open to settlement, so that in any consideration of the vacant

public lands an allowance should be made for a slight increase from the Indian reservations.

The forest reservations are a new institution, having been created by act of Congress of March 3, 1891.[1] Under this head has been included the Yellowstone National Park, as from its character and location it can best be classified in this category. The total extent of these reservations, including the Yellowstone Park, is only a trifle over 1 per cent of the whole area of the United States, and 13.21 per cent of the estimated extent of forest land of the Western States and Territories (p. 482).

The area disposed of is the balance obtained after deducting the vacant public lands, the various reservations, and the areas of the States having within their borders no lands belonging to the National Government. The total amount disposed of, as thus obtained, is 1,107,044 square miles, this being 37.27 per cent of the total land surface of the country. Of this amount 671,728 square miles, or 60.68 per cent of the total disposed of, is in the eastern part of the country, and the remainder, or 39.32 per cent, is in the West, these terms being defined, as used in this connection, on page 475.

The diagram, fig. 48, exhibits these facts in concise form. The circle is intended to represent by its area the entire land surface of the United States. This is divided into a number of sectors, proportional to the areas of the various classes of land. The area of the older States is shown to be relatively small, the single State of Texas being over half as large as all of the nineteen States forming the Union in the early part of this century. The sector showing the lands disposed of is divided by a dotted line indicating the relative amounts in the East and the West, and in the same way the sector showing vacant public lands is divided by a dotted line bringing out the relatively small proportion in the East.

IMPORTANCE OF HYDROGRAPHIC DATA.

By far the greater portion of the vacant public lands—over 95 per cent—are classed as arid or semiarid in character, and depend for their future value not so much upon altitude, mineral contents, or geological structure as upon the presence or absence of water. Thus it is that the question of water supply, its quantity, quality, and availability, is one upon which pivots the future of the national domain. When the essential facts concerning the water are clearly known, it will be possible to determine upon the best legislation for the reclamation of portions of this vast area and the dedication of other portions to various purposes, as for grazing and woodland. It is a fact now generally recognized that, owing to the scarcity of water, only a small proportion of the public domain can be reclaimed for agriculture, but this amount, though small when compared with the whole

[1] Statutes at Large, vol. 26, section 24, p. 1103.

area, is in the aggregate larger than the territorial extent of some of the States, and will sustain a population numbering millions. After all of the land that the water will cover has been utilized for agriculture by means of irrigation, there will still remain hundreds of millions of acres of rich land suitable for grazing and for the growth of forest products.

That the solution of the problems relating to the public lands of the United States depends upon a thorough knowledge of the hydrography can best be shown by a brief review of the conditions prevailing throughout the region where the greater part of this land is situated. At this time reference will not be made to the unoccupied tracts in the East, whose utilization depends to a large extent upon drainage, but to the great bodies of land within the western half of the United States whose one great need is that of water.

The streams within the arid regions of the United States have their sources amid the high, rocky, or forest-clad slopes of the mountains, and descend rapidly toward the fertile plains. Their downward course is seldom an uninterrupted one. Usually at one point or another they meander for a time through upper valleys or parks whose summer verdure is in striking contrast to the sunburned plains below. Leaving these, the streams enter rocky defiles or narrow canyons, to emerge upon a narrow lower valley, and, receiving tributaries on the way, they finally pass through the foothill region and out upon the vast fertile plains. At about this point a gradual transition takes place in the character of the channel, which, from a rocky, torrential, or gravelly stream-bed with rapid fall, broadens to a shallow, shifting, sandy channel, in which the stream, dividing and subdividing in times of low water, finally, by imperceptible degrees, loses itself. In times of flood the water may fill the broad, sandy waste and after a few days force its way far out to join some lake, or finally reach some perennial stream making its way to the ocean.

The water of the stream may be diverted at any point in its course. It may be taken out in the upper parks or valleys, high among the mountain peaks, and used during the spring or summer to increase the growth of the forage plants; or it may be utilized in the lower valleys among the foothills, or out upon the margin of the plain, or upon the lower plain itself. If the stream channel were like an iron pipe or conduit, in which the water, once received, must pass along until discharged into some branch or at the lower end, the consideration of water supply would be comparatively simple. It would be assumed that whatever water came into the pipe at any point must come out at some other, or, in other words, that the quantity to be dealt with would be constant, and our account books would balance. This, however, is not the case in nature. If among the mountains we measure all of the visible affluents of a stream and add together these measurements, and then measure the volume of the main stream a little distance below, we shall

generally find that the latter volume is greater than the sum of the visible tributaries. Water has come in impreceptibly. This action continues through a large part of the year, after the frost has left the ground and until late summer. Downstream, however, at the borders of the plain, the conditions are different. If at the edge of the foothills we measure all of the creeks, add together the measurements, and then measure the main stream a few miles below, it will usually be found that this latter volume is less than the sum of the various tributaries, and that this decrease continues at a greater or less rate, with perhaps an occasional increase.

This irregularity in the behavior of a stream in increasing and decreasing without visible cause is explained by what is commonly known as seepage or percolation. In the more elevated portions of the basin, with cooler climates and larger water supply, the rocks, more or less saturated, yield their waters to the streams, while in the lower and dryer part of the basin, the rocks and soils, being loose or unconsolidated, draw away some of the water, until all may be taken up and passed along and out into the atmosphere. Direct evaporation from the surface also diminishes the flow of streams in their lower courses, but this factor is relatively small and need not be dwelt upon here.

Under natural conditions, therefore, a stream gradually increases in volume, both by tributary surface streams and by percolation, and then gradually loses this volume by imperceptible degrees. There is thus a point where the stream, during medium stages, has greatest volume, and where losses are most negligible. This point is usually at or near the lower foothill region, and in a general way coincides with the place where, from slope of channel and other topographic features, canals and ditches can be most economically constructed to carry water out to the edge of the lower plain. This locality has other favorable conditions. Being protected by the foothills, its climate is often better than that of regions farther out upon the plain; the winds are not so severe, and the frosts do not come so early in the fall or linger so late in the spring.

Thus it is that in respect to character of soil, to climate, and to water supply and its economic use this part of the river basin is peculiarly favored for successful agriculture by irrigation; and if physical conditions only were to be considered, a proper distribution of efforts at such places would result in the largest and best utilization of the vast extent of public lands. Under the gradual development of agricultural interests, however, settlement has not taken place so as to produce the greatest good for the greatest number, partly on account of lack of broad knowledge of all of the facts, but more because individual necessities and individual choice governed the first undertakings. Thus it is that on each stream the best lands and the best opportunities for utilizing the water in a large way have often been neglected

and their utilization has been prevented for all time by innumerable petty projects or by adverse acquired rights.

The progress of settlement has been very irregular. A prospector weary with the search for precious minerals, a cattleman choosing a home ranch, or a pioneer farmer seeking a location with ample space for his growing family, has picked out what seemed to him at the time the most desirable spot, and by his own efforts, or aided perhaps by neighbors, has dug a small ditch where the ground was most easily worked by simple farm tools. Above or below another ditch has been taken out, and year by year, as more people settled along the stream, new ditches have been dug, far up the valley or lower down, and old ones have been enlarged. The taking out of the water by these little ditches and the resulting saturation of the ground has modified the natural seepage, and in the higher part of the stream channel, at least, the water taken out and put upon the ground in the early part of the season tends to find its way back to the channel later in the year. This is especially the case with the first or earlier ditches, for there being usually plenty of water in these, an amount in excess of the needs of the crops is used, and when the ground can hold no more this excess must be slowly distributed and finally, following the natural slopes, be discharged at the lowest points into the natural drainage lines. The tendency of such ditches, having drawn upon the spring flood and carried the water out upon the lands, is to add to the low-water seepage, or, in other words, to increase the volume later in the year. This tendency is now well recognized, and is often esteemed a benefit to lower portions of the valley, since it slightly diminishes the overflow in the spring, but more especially it is valuable by adding to the late summer discharge at times when the need of water is greatest.

The benefits to be derived from seepage water are, however, apt to be overestimated, and too great importance is likely to be assigned to them, especially by persons so located upstream that they have first use of the water. Take, for example, the typical catchment basin above described, in which there is a broad upper valley, a long middle or lower valley, and beyond this the broad expanse of margin of the plain. Inhabitants of the highest valley, by turning out water during the spring flood and distributing it over pasture or hay lands, put to beneficial use waters which otherwise would be wasted, since at that season there is an excess all along the stream. A part of the water thus utilized percolates back to the stream and adds to the volume available for the irrigators in the middle valley. If, however, this utilization in the highest valley continues throughout the summer, when the heat and consequent evaporation is greater, it may be possible to divert all of the flowing water from the stream by spreading it upon the fields, leaving the channel completely dry save for the seepage, which continues to flow. Then the inhabitants of the middle valley are deprived of the natural flow of the stream, and have only the seepage water, instead of

the ordinary discharge increased by seepage. There is thus a time shortly after the occurrence of the spring floods when continued utilization of the waters in the highest valley becomes not a benefit, but an injury, to the people below. The same thing is true of the utilization of the water in the middle valley. The extravagant use of the water early in the year in the middle valley may be of advantage to those below, by adding to the summer flow through seepage, but such use later in the season interferes greatly with the supply at points farther downstream by taking all of the water out of the stream.

There is for every point along a river of any considerable length a time when the diversion of the water at points far above becomes not a blessing, but a curse. This time varies not only with the amount of water in the stream and the amount taken out, but also with the weather conditions, a dry year resulting in diminished seepage and earlier passage of the critical point, and a cool year in retardation of the time when diversions above become an injury. This date, as a rule, gradually grows earlier and earlier as years go by, for with the usual extension of irrigating systems comes greater economy in the use of water, and with greater economy there must be less seepage. A smaller amount of water is put upon the fields, and finally only enough to supply the needs of the plants. When this point is reached there should theoretically be no artificially induced seepage, and then no benefit to points below. This, however, is an extreme condition, rarely realized. Although this critical time is somewhat uncertain and variable, it is essential that it be determined in a general way, if the rights of all persons are to be preserved and the farmers are to have protection in their water rights at all comparable to the security enjoyed in land titles.

The necessity of ascertaining not only the water supply, but also the modifications due to artificial diversion of the water, is emphasized by consideration of the prevalent customs and usual legislation regarding water rights. As a rule, throughout the arid region priority of utilization carries with it the first right to continued employment. The man who along the course of the stream first took out water and cultivated a given piece of land is by custom and law entitled forever to take out the same quantity of water to this land, regardless of his neighbors. The man who came second, whether by a day or by a generation, has a secondary right, and can use forever the amount of water originally diverted and put upon the cultivated soil, provided there is sufficient to supply the first comer. The man who is third in point of time can utilize his share only after the first and second men have had their prior claims satisfied; and so on down the list, the last comer being compelled, if necessary, to leave the water untouched until all have had the exact quantity legally claimed.

The above somewhat detailed discussion of one of the problems of water distribution illustrates the difficulties in the way of the best

development of the arid lands, and shows the necessity of thorough and accurate knowledge of all the conditions. The matter is further complicated by the manner in which political divisions have been drawn regardless of natural boundaries. In nearly all cases the more important streams flow through several counties, each of which has its own peculiar custom in regard to the distribution of water, and in each the inhabitants and officials are somewhat jealous of other counties, or at least are not inclined to work in harmony with them. The most difficult cases, however, are where State lines intersect drainage basins, as it is then almost impossible to secure any consideration by one State of the rights of people lower down the stream in another State. Each year these interstate questions are becoming more and more complicated, and the demand for laws or regulations which shall impartially settle the disputes is more urgent.

There are also important streams, such as the Rio Grande, which flow along or across the borders of the Republic and give rise to international complications similar in many respects to the interstate questions. While in each case there is necessity for accurate and detailed information regarding local conditions, yet it should be possible to determine some broad principles applicable to all. A thorough knowledge of the water supply, its fluctuations and limitations, is therefore essential, from whatever aspect the future of the public lands may be considered; but the difficulty of obtaining such systematic knowledge can not well be appreciated unless the vast extent and wide distribution of the national domain are considered. A conception of this can be best obtained by a brief examination of the relative areas of the various component parts of the United States.

AREA AND GROUPING OF THE SEVERAL STATES.

In this paper the figures relating to the areas of the several States and Territories are those given by Mr. Henry Gannett in Census Bulletin No. 23, dated January 21, 1891. According to this bulletin the total area of the United States, exclusive of Alaska, is 3,025,600 square miles. Of this 55,600 square miles is water surface, leaving 2,970,000 square miles of land surface. This is equivalent to 1,900,800,000 acres. For the purposes of this discussion the States may be considered in a number of groups, depending upon their relation to the public lands. The thirteen original States retained control of the lands within their present borders, and these lands, therefore, never formed a part of the national holdings. The total area of these thirteen States, including the District of Columbia, as shown on the next page, is 312,770 square miles, or 200,172,800 acres, this being a little over one-tenth of the present area of the United States.

Since the formation of the Union five States have been admitted within whose limits the National Government held no land. One of these—West Virginia—was cut off from the State of Virginia, while

the other four embraced lands claimed by one or another of the original States. The aggregate area of these five States is 145,425 square miles, this being a little less than 5 per cent of the present area of the country. At the time of its annexation the State of Texas was an independent Republic, and under the terms of admission it retained possession of the lands within its borders. The State has had its own land office and system of administering public lands, so that its addition to the Union did not increase the extent of the national holdings. Although the conditions are somewhat similar to those in the admitted States above mentioned, yet Texas, on account of its position and large size, can not well be grouped with these, but stands by itself. For convenience of reference the following table gives the area of the land surface of the thirteen original States and of the five States admitted later within which the National Government has not owned the vacant land, and also of Texas:

Area of the land surface of the older States.

States.	Square miles.	Acres.	Per cent of land area of United States.
New Hampshire	9,005	5,763,200	.30
Massachusetts	8,040	5,145,600	.27
Rhode Island	1,085	694,400	.04
Connecticut	4,845	3,100,800	.16
New York	47,620	30,476,800	1.60
New Jersey	7,455	4,771,200	.25
Pennsylvania	44,985	28,790,400	1.51
Delaware	1,960	1,254,400	.07
Maryland	9,860	6,310,400	.33
Virginia	40,125	25,680,000	1.35
North Carolina	48,580	31,091,200	1.63
South Carolina	30,170	19,308,800	1.02
Georgia	58,980	37,747,200	2.00
District of Columbia	60	38,400	.....
Total, 13 States and District of Columbia	312,770	200,172,800	10.53
Kentucky	40,000	25,600,000	1.35
Vermont	9,135	5,846,400	.30
Tennessee	41,750	26,720,000	1.40
Maine	29,895	19,132,800	1.01
West Virginia	24,645	15,772,800	.83
Total, 5 States	145,425	93,072,000	4.89
Texas	262,290	167,865,600	8.83
Total, 19 States and District of Columbia	720,485	461,110,400	24.25

Deducting the nineteen States above mentioned and the District of Columbia, there are left the public-land States proper, including with these the Territories. These comprise in area a little over three-fourths of the whole extent of the United States. The lands within their borders have, since the birth of the Republic, been a source of revenue and of strength. The common interest in this vast property has been a tie to bind the sometimes clashing interests of the various sections, and the broad extent of fertile lands has served to divert and turn to account the energies of the overcrowded or restless population of the East.

Of the public-land States there are only four in which all of the vacant land has been disposed of. These are Illinois, Indiana, Iowa, and Ohio. The remaining States and Territories have from less than 1 per cent up to 99 per cent of their area still vacant. These remaining States arrange themselves naturally into two groups, the Eastern and the Western. Under the head of Eastern States are included all those lying east of the center of the country. As the map of the United States is usually drawn, the ninety-seventh meridian forms the central vertical line. On the north this coincides approximately with the position of the Red River of the North, forming the boundary between northern Minnesota and North Dakota. South of this river, a series of State boundaries forms an irregular line having a trend slightly to the east of south to the Gulf of Mexico. This somewhat arbitrary line affords a convenient means of dividing the public-land States, since it separates as a whole the humid States from those which are wholly or in part arid or subhumid. The natural line of demarcation between these great climatic divisions lies somewhat farther west, but is nowhere sharply defined, and may be considered as oscillating year by year, backward and forward, over a considerable belt of country. On account of this uncertainty as to the natural division, it is necessary in discussing the public lands to take some such fixed line as that afforded by the State boundaries. Nearly all of the public lands to the east of this line are not only well watered, but many of them are swampy in character, while the greater part of the public lands to the west are arid and almost desert-like.

The following tables give the area of the States of the two groups above mentioned, both in square miles and in acres, and the size of these as compared to the country as a whole. On inspection, it will be seen that over one-half of the area of the country is included within the Western public-land States and Territories, and in this connection it should be stated that 61.48 per cent is still unoccupied.

Area of the land surface of the Eastern public-land States.

States.	Square miles.	Acres.	Per cent of land area of United States.
Alabama	51,540	32,985,600	1.74
Arkansas	53,045	33,948,800	1.79
Florida	54,240	34,713,600	1.83
Illinois	56,000	35,840,000	1.88
Indiana	35,910	22,982,400	1.21
Iowa	55,475	35,504,000	1.87
Louisiana	45,420	29,068,800	1.53
Michigan	57,430	36,755,200	1.93
Minnesota	79,205	50,691,200	2.67
Mississippi	46,340	29,657,600	1.56
Missouri	68,735	43,990,400	2.31
Ohio	40,760	26,086,400	1.37
Wisconsin	54,450	34,848,000	1.83
Total Eastern States	698,550	447,072,000	23.52

Area of the land surface of the Western public-land States and Territories.

States.	Square miles.	Acres.	Per cent of land area of United States.
California	155,980	99,827,200	5.25
Colorado	103,645	66,332,800	3.49
Idaho	84,290	53,945.600	2.84
Kansas	81,700	52,288,000	2.75
Montana	145,310	92,998,400	4.90
Nebraska	76,840	49,177,600	2.59
Nevada	109,740	70,233,600	3.69
North Dakota	70,195	44,924,800	2.36
Oregon	94,560	60,518,400	3.18
South Dakota	76,850	49,184,000	2.59
Washington	66,880	42,803,200	2.25
Wyoming	97,575	62,448,000	3.29
Total Western States	1,163,565	744,681,600	39.18
Territories.			
Arizona	112,920	72,268,800	3.80
Indian Territory	31,000	19,840,000	1.04
New Mexico	122,460	78,374,400	4.12
Oklahoma	38,830	24,851,200	1.31
Utah	82,190	52,601,600	2.77
Total Territories	387,400	247,936,000	13.04
Total Western States and Territories	1,550,965	992,617,600	52.22

EASTERN PUBLIC-LAND STATES.

AREA AND RATE OF DISPOSAL OF VACANT LANDS.

The table on page 477, compiled from the report of the General Land Office, gives the area of public lands vacant in the States lying east of the center of the country, except in Illinois, Indiana, Iowa, and Ohio, where there are no longer any vacant lands, the National Government having disposed of its possessions in these four States. In the nine remaining States the vacant area varies from a little under 1,000 up to 8,787 square miles. The aggregate amount is 26,822 square miles, or 17,166,080 acres, this being 5.25 per cent of the total area of the nine States within which this land is situated. The figures given under the head of "Rate of disposal" show the average number of square miles to which title has been acquired annually by individuals or corporations during the past five years. They represent the rate at which the vacant land is passing out of the hands of the General Government, although this rate has been varying, and as a whole decreasing. The ratio which these disposals bear to the lands remaining vacant is also shown in the table, varying by States from over 37 per cent in Wisconsin to less than 6 per cent in Arkansas. As a whole, the rate has been 11.58 per cent; or, in other words, if this rate should be maintained, all the lands would be disposed of in about nine years. As previously stated, however, this rate tends to decrease as the better land is exhausted; but it is safe to assume that within a decade the amount of vacant public land within these States will be insignificant.

Nearly 60 per cent of the total area vacant lies in the States of Arkansas and Minnesota. Next to these come Florida and Louisiana; and then, in order, Missouri, Mississippi, Alabama, Wisconsin, and Michigan. Much of the vacant land in the two States first named is rugged and timber-clad, with a soil reputed to be too poor for successful agriculture. On the other hand, in Florida and Louisiana the greater part of the vacant land is swampy and can be reclaimed, if at all, only at considerable expense for drainage canals and dikes or levees to prevent overflow. In the remaining States the lands are largely timbered, and some of them may be valuable not only for forest products but also for agricultural purposes. In all of the States these tracts of vacant land are, as a rule, widely scattered in relatively small bodies, and are not in such condition as to attract the settler.

Total land surface, area vacant, and the rate of disposal in Eastern public-land States.

States.	Total land surface. *a*	Lands vacant.		Rate of disposal.		
		Area.	Per cent of land surface.	Annual average in five years.	Per cent of vacant lands in State.	Per cent of total area of State.
	Sq. miles.	*Sq. miles.*		*Sq. miles.*		
Alabama	51,540	1,258	2.44	404	32.11	0.78
Arkansas	53,045	7,238	13.64	407	5.62	.77
Florida	54,240	3,141	5.79	300	9.55	.55
Louisiana	45,420	1,660	3.06	314	18.91	.69
Michigan	57,430	986	1.73	164	16.63	.28
Minnesota	79,205	8,787	11.09	643	7.32	.80
Mississippi	46,340	1,307	2.82	355	27.16	.77
Missouri	68,735	1,400	2.04	323	23.07	.48
Wisconsin	54,450	1,045	1.91	197	37.86	.36
Total	510,405	26,822	5.25	3,107	11.58	.61

a These figures are from Bulletin No. 23 of the Eleventh Census, prepared by Henry Gannett, dated January 21, 1891.

WESTERN PUBLIC-LAND STATES.

AREA AND RATE OF DISPOSAL OF VACANT LANDS.

Under the head of Western public-land States are grouped not only States but also five Territories—Arizona, Indian Territory, New Mexico, Oklahoma, and Utah. In this category are included North Dakota, South Dakota, Nebraska, and Kansas; for although the eastern ends of these lie well within the humid region and project into the eastern part of the United States, yet the vacant public lands of these States are for the most part in their western halves, and are all either arid or semiarid in character, and therefore, for purposes of discussion, they may be considered as belonging to the arid part of the country. Texas, also, would be included in this division but for the fact, as previously stated, that this State, coming into the Union as an independent Republic, retained possession of its own lands, most of which have been disposed of according to land laws and a system peculiar to the State.

Total land surface, area disposed of, reserved, and vacant in Western public-land States.

States. *a*	Land surface. *b*	Area disposed of.		Area reserved.		Area vacant.	
	Sq. miles.	*Sq. miles.*	*Per ct.*	*Sq. miles.*	*Per ct.*	*Sq. miles.*	*Per ct.*
Arizona	112,920	6,634	5.87	20,378	18.05	85,908	76.08
California	155,980	56,445	36.19	9,320	5.98	90.215	57.83
Colorado	103,645	30,104	29.04	6,607	6.38	66,934	64.58
Idaho	84,290	5,708	6.77	3,483	4.13	75,099	89.10
Indian Territory	31,000	.....	.....	31.000	100	.....	.....
Kansas	81,700	80,410	98.42	150	.18	1,140	1.40
Montana	145,310	16,196	11.14	15,057	10.37	114,057	78.49
Nebraska	76,840	59,358	77.25	296	.39	17,186	22.36
Nevada	109,740	3,906	3.55	1,263	1.15	104,571	95.30
New Mexico	122,460	29,688	24.24	7,470	6.10	85,302	69.66
North Dakota	70,195	30,169	42.98	6,936	9.88	33,090	47.14
Oklahoma	38,830	12,302	31.68	11,315	29.14	15,213	39.18
Oregon	94,560	28,581	30.23	10,092	10.67	55,887	59.10
South Dakota	76,850	35,695	46.45	15,951	20.76	25,204	32.79
Utah	82,190	7,812	9.51	7,070	8.60	67,308	81.89
Washington	66,880	26,257	39.26	7,866	11.76	32,757	48.98
Wyoming	97,575	6,051	6.20	7,880	8.08	83,644	85.72
Total	1,550,965	435,316	28.07	162,134	10.45	953,515	61.48

a Including five Territories.
b Area as given by Henry Gannett in Bulletin No. 23 of the Eleventh Census.

The relative areas vacant, reserved, and disposed of, given in the above table, are graphically exhibited in the accompanying diagram, fig. 49. In this the length of each horizontal bar indicates the total area of the State or Territory; the uncolored part designates the area now vacant; the diagonally lined portion represents the area reserved (much of which will ultimately be thrown open to settlement), and the black part shows the extent to which the land has passed out of the hands of the National Government. As shown by this diagram, the greatest amount of vacant public land is in Montana, where there are over 114,000 square miles still open. The greatest proportion, however, is in Nevada, where, according to the estimates, over 95 per cent of the total area is still at the disposal of Congress. Next to Montana and Nevada, in the order of extent of vacant lands, is California, with over 90,000 square miles, this being, however, a little more than one-half the total area of the State. Next come Wyoming and New Mexico, each having about the same amount of vacant land.

The smallest area of vacant public land in any Western State is in Kansas, where the amount still in the hands of the National Government is less than 2 per cent. This State, if consideration is had only of the area of its public lands, hardly belongs in this category, but should be classified with Iowa and other of the States east of the center of the country. The disposal of the lands in the western end of the State was, however, largely the result of misapprehension of their character, and was due to a series of waves of popular excitement, or "booms," by which settlers were induced to locate where many of them have since found it impossible to make a living. As a consequence, although the National Government has parted with thousands and even millions of acres of this Western land, yet to all intents and purposes it is still vacant and unutilized.

Next above Kansas, in order of area of vacant land, comes Oklahoma, with an estimated area of about 15,000 square miles, mainly in the western portion of that Territory and in the long strip of Beaver County, often designated "No Man's Land." This country is similar in character to western Kansas and eastern Colorado, being unsuitable for settlement except at the relatively few points where water can be had. It is, however, admirably adapted to grazing, and must ultimately

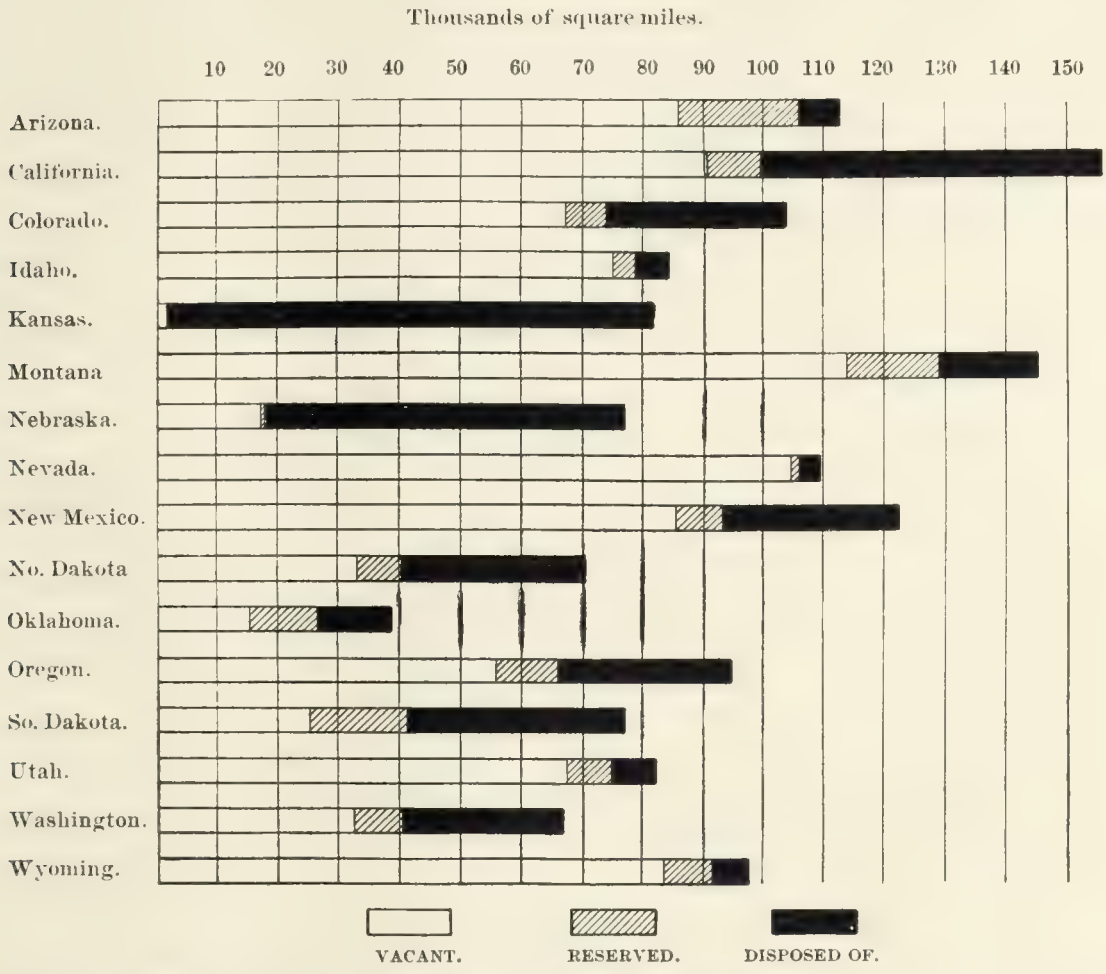


FIG. 49.—Diagram illustrating relative areas of Western States and Territories, and the areas vacant, reserved, and disposed of.

be used largely for this purpose. Nebraska, with about 17,000 square miles, comes next, its vacant land, as shown by the map, being also mainly in the western end and north of the Platte River.

GENERAL CHARACTER OF THE LANDS.

Before discussing the lands disposed of, reserved, and vacant, and their water supply, it is essential to have a clear conception of the physical characteristics of the Western public-land States as a whole. This part of the country embraces a wider range of climatic and topographic conditions than that of the Eastern part. It includes vast mountain ranges whose summits are perpetually covered with snow, and broad, almost impassable deserts, alternately burned by a semitropical sun or

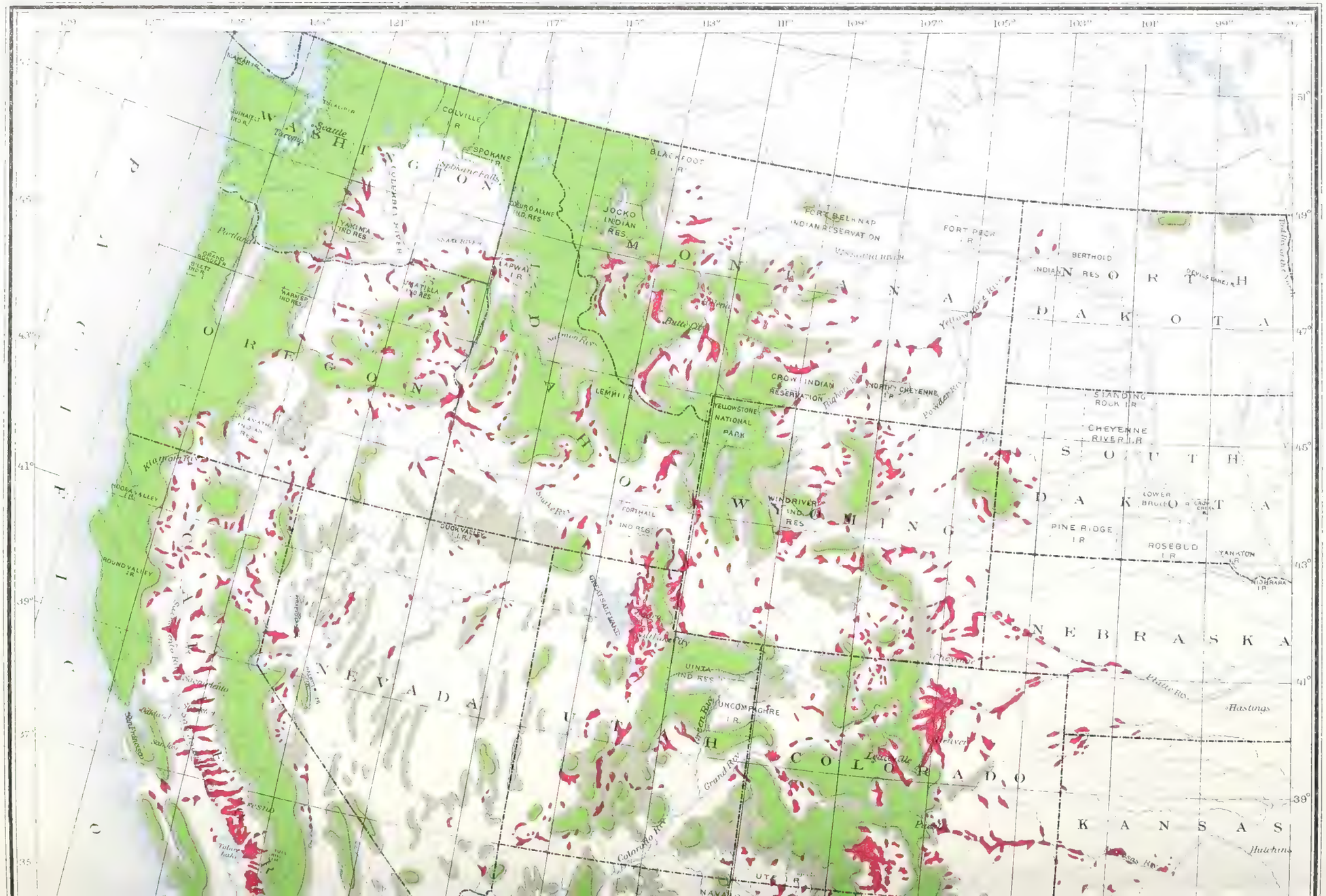
chilled by arctic blasts. On the east are boundless prairies and plains, gradually rising to the plateau upon which stand the Rocky Mountains, these treeless regions at times clothed with luxuriant vegetation and again parched with seemingly endless drought. West of the Rocky Mountains is the broad Interior Basin, from which no waters escape to the sea—a region of intense sunshine and extreme drought. This is a land of precipitous mountains, whose bases are surrounded and buried by valley deposits level as a floor, showing unmistakable evidence of the comparatively recent existence of extensive bodies of water. On the west rise the great ranges of the Sierra Nevada and Cascade, their summits piercing the clouds and drawing from them the waters which, in the form of rivers, furrow the steep slopes. Beyond these are the valleys of the Pacific Slope, with their wonderfully fertile soil, and between them and the ocean are the irregular coast ranges, forming rocky and often inhospitable shores. On the south is a warm, almost tropical climate, suitable to the development, under high cultivation, of many of the most valuable fruits; and toward the north are colder, more rigorous conditions, favorable to the growth of cereals.

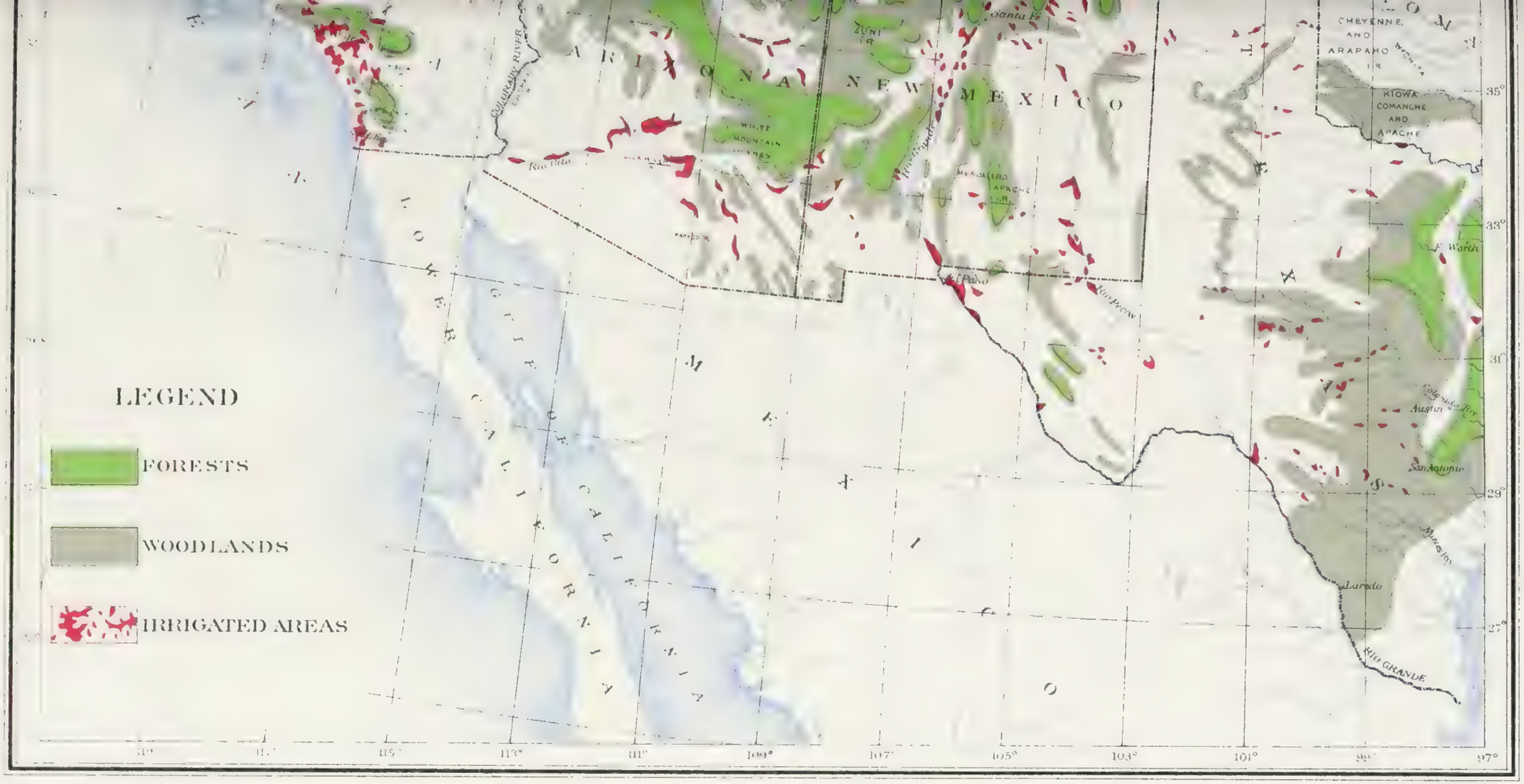
The greater part of the surface of these Western public-land States is well known to be arid—that is, the precipitation in the form of rain or snow does not occur in sufficient quantities or at the right times to render profitable the cultivation of the ordinary crops. It is not possible in this general review to enter into the details of the rainfall and of its time of occurrence; that subject has been presented more completely in various reports of the Signal Service, of the Weather Bureau, and of this Survey.[1]

Although the country as a whole is arid, yet there are considerable areas, especially on the high mountains, at one time covered by forests, and in scattered localities well within the arid region, where crops are often raised without irrigation. By far the larger proportion of the surface supports a great number and variety of plants adapted to withstand drought, many of the grasses being of high value for grazing. Although scanty, the herbage is usually sufficient to furnish food for flocks or herds, and the arid region as a whole may be considered as a great grazing land, with occasional desert areas, and, more rarely, with spots where, under careful cultivation, fair crops can be produced, or where, through unusual precipitation, trees have obtained a foothold. The soil, especially that of the plains and broad valleys, is of great fertility, having been exposed for countless years to the disintegrating influences of the weather, and its material suitable for plant food not having been drawn upon to any considerable extent.

The accompanying map (Pl. XXXVI) exhibits the relative position of the wooded areas and grazing and irrigated lands west of the ninety-

[1] Thirteenth Annual Report United States Geological Survey, Part 3, Irrigation, p. 27; Fourteenth Annual Report United States Geological Survey, p. 152, Plate VI. The first of these reports gives a diagram of the mean monthly distribution of precipitation at various points in the West, and the second, by means of a map, shows the mean annual distribution over the whole country.


WASHINGTON
OREGON
IDAHO
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
COLORADO
UTAH
NEVADA
WYOMING
Seattle
Tacoma
Spokane Falls
Portland
COLVILLE I.R.
SPOKANE I.R.
COEUR D'ALENE IND. RES.
JOCKO INDIAN RES.
BLACKFOOT I.R.
FORT BELKNAP INDIAN RESERVATION
FORT PECK I.R.
BERTHOLD INDIAN RES.
DEVILS LAKE I.R.
YAKIMA IND. RES.
LAPWAI I.R.
UMATILLA IND. RES.
WARM SPRINGS IND. RES.
GRAND RONDE IND. RES.
SILETZ IND. RES.
QUINAIELT IND. R.
TULALIP I.R.
LEMHI I.R.
CROW INDIAN RESERVATION
NORTHERN CHEYENNE I.R.
YELLOWSTONE NATIONAL PARK
STANDING ROCK I.R.
CHEYENNE RIVER I.R.
LOWER BRULE
CROW CREEK I.R.
PINE RIDGE I.R.
ROSEBUD I.R.
YANKTON I.R.
NIOBRARA I.R.
WIND RIVER IND. RES.
FORT HALL IND. RES.
DUCK VALLEY I.R.
MOUNT VALLEY I.R.
MOOKA VALLEY I.R.
KLAMATH I.R.
GREAT SALT LAKE
Salt Lake City
UINTA IND. RES.
UNCOMPAHGRE I.R.
UTE I.R.
Denver
Hastings
Hutchins
Colorado R.
Grand R.
Green R.
Snake R.
Columbia R.
Yellowstone R.
Missouri R.
Platte R.
Kansas R.
Arkansas R.
Cheyenne R.
Powder R.
Big Horn R.
Clark's Fork
Pend Oreille L.
Flathead L.
Great Salt Lake
Sacramento
San Francisco
San Joaquin R.
Sierra Nevada
Silver City
Virginia City
Salt Lake City
Denver
Pueblo
Leadville
Butte City
Helena
Missoula
Spokane Falls
Tacoma
Seattle
Portland
Hastings
Hutchins



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RELATIVE LOCATION OF

FORESTS, WOODLANDS AND IRRIGATED AREAS

IN THE

WESTERN PART OF THE UNITED STATES

BY F. H. NEWELL.

Scale.

100 0 100 200 300 400 500 MILES

1895.

seventh meridian. On the map the wooded portions are divided into two classes—districts in which a considerable number of trees are suitable for timber, colored dark green, and districts in which the greater part of the growth is scattering or is so small that the wood is valuable only for fuel, fence posts, or occasionally for mine props. Areas of this latter character are denoted on the map by a sage color. They are seen to fringe to a great extent the forested areas and to cap

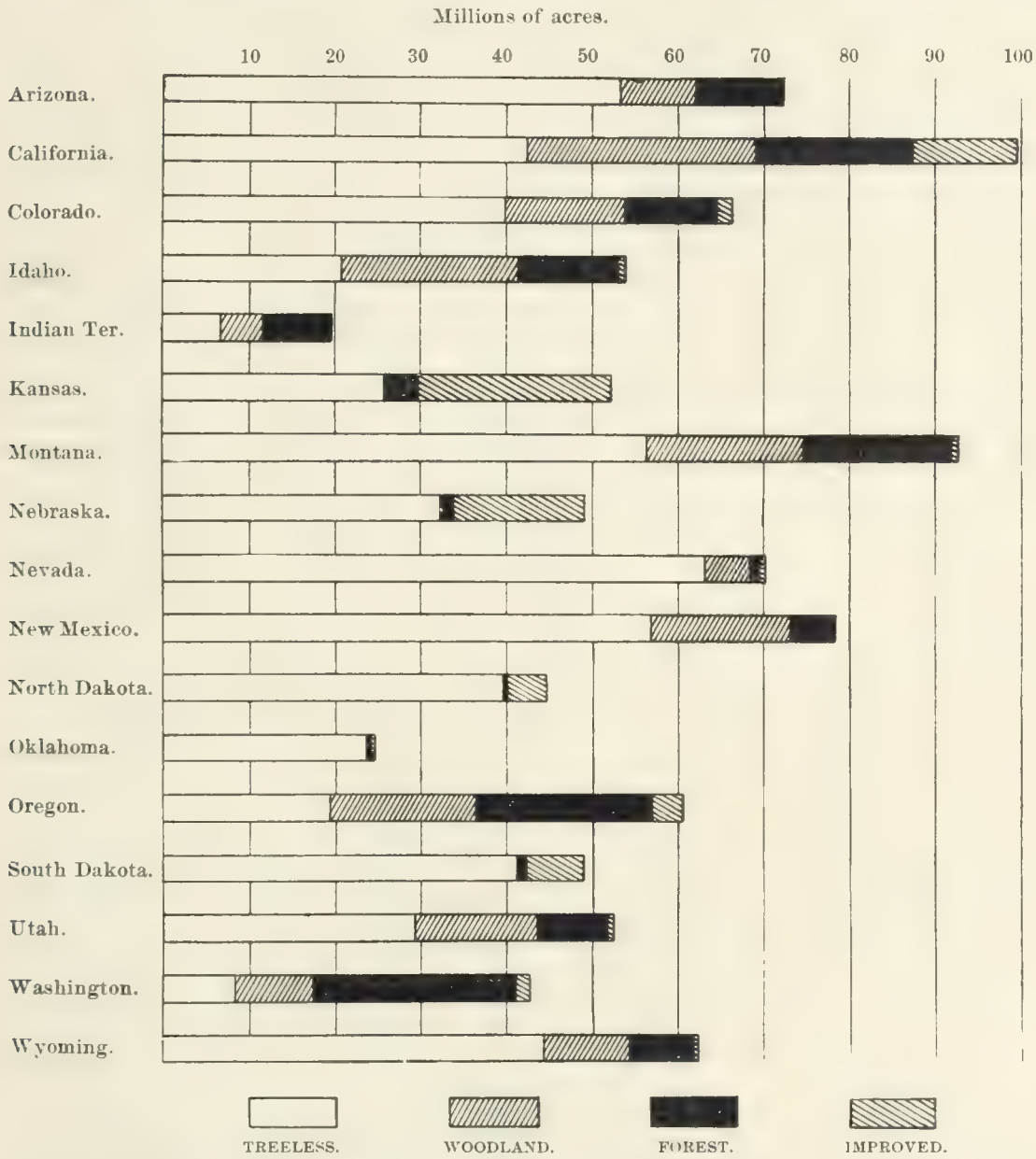


FIG. 50.—Diagram illustrating relative areas of forest, woodland, treeless, and improved land in the Western States.

the mountains or broad plateaus where a heavier growth has not been possible. The uncolored portions of the map represent for the most part the great body of the grazing lands, while the red spots show the location of the areas irrigated. A map of woodlands, similar to this and prepared from the same data, has been published by Mr. B. E. Fernow, Chief of the Division of Forestry, in the report of the Secretary of Agriculture for 1893, page 317.

An estimate of the areas of forest and small trees, and of open or treeless areas, has been prepared, giving in round numbers the probable extent of these various classes of lands. These figures relate to climatic and soil conditions favorable to forest and tree growth rather than to existing forests as partly destroyed by artificial agencies. In many cases vast tracts have been burned over, injuring the merchantable timber, but Nature will do her part in restoring the growth if the young trees are protected from fire, cattle, and sheep. There is need of more accurate information in regard to the extent and value of the natural woodlands of the West, the matter being one concerning which many contradictory opinions have been held, and very little accurate knowledge is obtainable. The figures submitted, however, are believed to be as nearly correct as they can be made at the present time, although in detail they may be subject to considerable criticism.

The following table gives, in acres, the land surface of each State and Territory, and, in round numbers, the estimated area originally covered by forest and by scattered trees, here designated as woodland. The discrimination between forest and woodland is of course largely a matter of personal opinion, as the one shades into the other, and trees which in one locality are regarded as useless are of considerable value in another, where timber is scarce. After these is shown the extent of the treeless or open country, this being the remainder after deducting the forest, woodland, and improved areas. The last column shows the number of acres of improved land, as published by the census for 1890. These facts are shown in graphic form in fig. 50, page 481.

Forest, woodland, treeless, and improved areas in Western public-land States.

States and Territories.	Land surface.	Forest. *a*	Woodland.	Treeless.	Improved. *b*
	Acres.	*Acres.*	*Acres.*	*Acres.*	*Acres.*
Arizona	72, 268, 800	10, 000, 000	8, 700, 000	53, 464, 672	104, 128
California	99, 827, 200	18, 000, 000	27, 000, 000	42, 604, 361	12, 222, 839
Colorado	66, 332, 800	10, 600, 000	14, 000, 000	39, 909, 280	1, 823, 520
Idaho	53, 945, 600	10, 800, 000	21, 600, 000	20, 939, 238	606, 362
Indian Territory	19, 840, 000	8, 000, 000	5, 000, 000	6, 840, 000	.....
Kansas	52, 288, 000	4, 000, 000	.....	25, 984, 699	22, 303, 301
Montana	92, 998, 400	17, 000, 000	18, 600, 000	56, 482, 883	915, 517
Nebraska	49, 177, 600	1, 500, 000	.....	32, 429, 895	15, 247, 705
Nevada	70, 233, 600	1, 000, 000	5, 300, 000	63, 210, 548	723, 052
New Mexico	78, 374, 400	4, 700, 000	16, 500, 000	56, 911, 294	263, 106
North Dakota	44, 924, 800	400, 000	.....	39, 866, 785	4, 658, 015
Oklahoma	24, 851, 200	500, 000	.....	23, 787, 472	563, 728
Oregon	60, 518, 400	20, 600, 000	17, 000, 000	19, 402, 400	3, 516, 000
South Dakota	49, 184, 000	1, 000, 000	.....	41, 224, 707	6, 959, 293
Utah	52, 601, 600	8, 400, 000	14, 200, 000	29, 453, 377	548, 223
Washington	42, 803, 200	23, 500, 000	9, 000, 000	8, 482, 368	1, 820, 832
Wyoming	62, 448, 000	7, 500, 000	10, 000. 000	44, 471, 169	476, 831
Total	992, 617, 600	147, 500, 000	166, 900, 000	605, 465, 148	72, 752, 452
Per cent	100	14. 86	16. 81	61	7. 33

a Report of the Secretary of Agriculture for 1893, pp. 317, 318.
b Abstract of the Eleventh Census 1890, Washington, 1894, pp. 62, 63.

A second estimate has been prepared to show, in round numbers, the extent of grazing, wooded, forest, and desert areas within the arid and semiarid portions of the Western public-land States. In preparing this

the figures previously given have been used, selection being made somewhat arbitrarily of those portions of the States of Washington, Oregon, and California which may be considered as humid. The table shows, therefore, the relative proportion of these four classes of land in each of the States and Territories, and exhibits in a general way the natural resources of the various divisions of the regions where water is of prime importance.

Grazing, woodland, forest, and desert areas within the arid and semiarid portions of the Western public-land States.

States and Territories.	Grazing.	Wooded.	Forest.	Desert.
	Acres.	*Acres.*	*Acres.*	*Acres.*
Arizona	38,000,000	8,700,000	10,000,000	15,000,000
California	20,000,000	6,000,000	4,000,000	20,000,000
Colorado	40,000,000	14,000,000	10,600,000	.....
Idaho	20,000,000	19,000,000	8,000,000	.....
Kansas	15,000,000	.....	.....	.....
Montana	56,000,000	15,000,000	15,000,000	.....
Nebraska	25,000,000	.....	.....	.....
Nevada	43,000,000	5,300,000	1,000,000	20,000,000
New Mexico	57,000,000	16,500,000	4,700,000	.....
North Dakota	25,000,000	.....	.....	.....
Oklahoma	20,000,000	.....	.....	.....
Oregon	15,000,000	7,000,000	4,000,000	.....
South Dakota	30,000,000	.....	500,000	.....
Utah	20,000,000	14,200,000	8,400,000	10,000,000
Washington	8,000,000	3,000,000	2,000,000	.....
Wyoming	39,000,000	10,000,000	7,500,000	5,000,000
Total	471,000,000	118,700,000	75,700,000	70,000,000

Grazing lands.—As shown by the table on page 482, over 600,000,000 acres, or more than three-fifths of the entire area of the Western public-land States, consists of open, treeless country. Although there is not a sufficient supply of moisture to support or encourage the growth of trees upon the greater part of this vast area, yet almost everywhere herbage of one kind or another has succeeded in obtaining a foothold, and during portions of the year, at least, furnishes excellent grazing. The soil of this country is usually very fertile, but the investigations of water supply have shown that it is highly improbable that a sufficient quantity of water can ever be obtained to reclaim more than a very small percentage of these arable lands. The greater part must always remain uncultivated, except in so far as plants adapted to arid conditions may be introduced.

The great bulk of the area of the Western public-land States as a whole consists of grazing lands, and it may truly be said that one of the greatest problems, upon whose solution the prosperity of the West depends, is the wise and efficient control of the grazing industries. As previously stated, all of the vacant public lands are open, and can be grazed over by the flocks and herds of any person. With free pasturage, the sheep and cattle business has in the past been one of enormous profits. The natural increase being rapid, comparatively small capital was required at the outset. Herds raised in one State or Territory are driven hundreds, and even thousands, of miles to and fro across the public domain, going north in summer and south in winter,

or from remote portions of the West nearer to the markets of the East. As a result of the large profits obtained in the past, herds of cattle and flocks of sheep have been allowed to increase to such an extent that the free ranges, including both woodland and treeless areas, although embracing almost one-half of the United States, have been overstocked, and many of the valuable native grasses have been eaten down so closely by the sheep, or so trampled underfoot, that it is reported that over vast extents of country not a single useful plant can now be found.

The settler, with his small herd out on the vast tract of the public domain, may try to preserve some of the valuable grazing lands about him, but the wandering cattleman, or worse, the sheepman with his flocks numbering thousands, may at any time pass over the country, and in a few days, or even hours, the ground is as bare as though blasted by years of drought. Permanency of occupation is thus discouraged, and the nomadic life, with its accompaniment of lawlessness and indifference to the future and to the public good, is forced upon the pioneer.

Wooded areas.—On the map, Pl. XXXVI, an attempt has been made to divide the wooded areas into two groups, those on which trees of sufficient size to furnish merchantable timber have grown, and those where the natural conditions are such that the trees are so small or scattering as to be useful only for firewood, fence posts, or mining purposes. The former area includes the great forests of the West, these being found mainly upon the high, rocky slopes of the Sierra Nevada, Cascade, and Coast Ranges, where, under favorable climatic conditions, some of the largest and most valuable timber of the country is grown. These forest areas, colored green, are shown also as extending along the ranges of northern Idaho and western Montana and the irregular mountain masses of Utah, Colorado, Arizona, and New Mexico. Many tree-covered areas in the Rocky Mountain region have been designated forests, although the size and character of the trees are such that if they were in California or western Oregon they would be considered as fit only for fuel. The scarcity of timber and the demand for anything that can be cut into merchantable size causes trees which would be considered worthless in one part of the country to be cut and manufactured into lumber in another.

The term "woodland" has been used in the table to designate those areas where the trees or large shrubs, although of no especial value for timber, furnish firewood and material for the construction of fences and of shelter for cattle, and thus supply some of the needs of the settler. It also includes considerable areas of small trees, sufficiently large to be used as props in mines, and even the growths or thickets of dwarfed oaks and the larger growth of bushes classed by the frontiersmen under the general term "chaparral." As a rule, it may be said that where these scattering trees are found there is excellent grazing among them; and therefore, although this area of nearly 167,000,000 acres is classed as woodland, it has a hardly less value for grazing purposes.

Desert lands.—The area of land which is desert and probably worthless has been found in the progress of settlement to be relatively small. Before the West was thoroughly explored and well known it was generally considered that the greater part was absolutely valueless, but with the introduction of irrigation and of methods of agriculture suited to the climate, with the provision of water for cattle, and especially with the facilities for rapid transportation, it has been found possible to utilize for cultivation or grazing nearly all the lands which were previously considered barren and rocky wastes.

It is of course impossible to discriminate with any degree of exactness between lands which at one time or another support for a few weeks or months a scanty growth sufficient for grazing purposes, and those which are at all times so barren that cattle can not find means of sustenance. It has been estimated, however, that there are in all about 70,000,000 acres of such desert lands (p. 483). Of this, 15,000,000 acres are in southern and southwestern Arizona; 20,000,000 acres are in southern California, north and east of the San Bernardino Mountains and adjacent to Nevada and Arizona; 20,000,000 acres are in southern and eastern Nevada; 10,000,000 acres are in Utah, west of Great Salt Lake; and 5,000,000 acres are in Wyoming, in the southwestern portion, near the head of Green River.

Improved and irrigated lands.—The table on page 482 shows that out of the entire extent of the Western public-land States only about 72,752,452 acres, or 7.33 per cent, was improved at the time of the Eleventh Census, in 1890. Of this the greater part was in Kansas, Nebraska, and the Dakotas, leaving only 23,584,138 acres in the States and Territories within the arid region. A large portion of this improved land, especially in California, Oregon, and Washington, lies within the strip of humid country adjacent to the Pacific Coast. Making due allowance for this, it has been estimated that only between 1 and 2 per cent of the arid region can be designated as improved.

The area actually cultivated is far less than the amount above given, and the extent redeemed by irrigation is relatively insignificant. According to the last census there were in the arid and subhumid lands only 3,631,381 acres irrigated, this being about one-half of 1 per cent of the area of the States within which irrigation was largely practiced. Since 1890 there has been a considerable extension of the area cultivated by the artificial application of water, but concerning this there are no reliable figures. Owing to the depressed industrial condition of the West during 1893, 1894, and 1895, it is highly improbable that more than double this amount was actually cultivated in this manner, although claims are made that considerably larger acreages were covered with water. Making liberal allowances, it is estimated that not more than 1 per cent of the arid lands is now irrigated and tilled.

It is not generally appreciated that a considerable area of land, even within the borders of the arid region, is cultivated each year by what

is there known as "dry farming." By taking advantage of local conditions of rainfall, by thorough cultivation, and by the selection of crops which withstand a considerable drought or which mature before the extreme heat of the year is felt, it has been found possible to obtain profitable crops in a few localities in each arid State. The production per acre is usually small, but it is possible to compensate for this low average value by tilling large areas of the fertile, easily worked soil. The accompanying map (fig. 51) is intended to show in a general way

FIG. 51.—Areas within which dry farming is attempted.

by the groups of black dots the lands upon which crops have been raised occasionally without the artificial application of water. On the east the solid black indicates the debatable ground between the region in which irrigation is not considered necessary and that which is known to be too arid for successful agriculture without irrigation. The area within which "dry farming" is occasionally successful is seen to extend across Kansas and into eastern Colorado, following the divide between the Platte and Arkansas drainage as far west as the foothills of the Rocky Mountains. All through this country fair crops have occasionally been

obtained, but as a rule the farmers can not be said to be successful, the results of a fortunate year not compensating for continued losses at other times.

Along the Rocky Mountain region from western Montana southerly through northern Utah[1] to the high plateaus of Arizona are occasional spots where, within or near the wooded lands, farmers plant grain, potatoes, and sometimes other crops with a fair degree of success. There is little, however, to recommend dry farming, except the fact that occasionally something can be raised in this manner, and it is usually impossible at these high altitudes, with the means at hand, to obtain water. Farther west, in eastern Washington and northern Oregon, are considerable tracts bordering the Blue Mountains and the ranges of northern Idaho in which dry farming is attempted. The structure of the soil is such that the supply of moisture received, although apparently scanty, suffices to produce large crops of cereals, and these lands, while considered well within the arid region, are noted for their productiveness. The remaining areas of black spots near or parallel to the Pacific Coast represent the lands cultivated in the valleys west of the Cascade and Sierra Nevada ranges. These, as a rule, receive considerable rainfall except during the latter part of the summer season, but in the case of the southern part of the San Joaquin Valley the precipitation is very slight, and dry farming on a large scale is being replaced by the irrigation of small tracts.

LANDS DISPOSED OF.

As shown by a preceding table (p. 478), the lands disposed of in the Western public-land States have been estimated at 278,602,289 acres, or 435,316 square miles, this being a trifle over 28 per cent of the total area of these States and Territories. This estimate has been prepared from the reports of the General Land Office.[2]

In the following table these lands have been divided into three classes—those disposed of to railroad corporations as an inducement or aid to the original construction of the railroads, the swamp lands granted to the States, and private and miscellaneous disposals, for the most part to individuals for homes.

[1] Report on Agriculture by Irrigation in the Western Part of the United States at the Eleventh Census, 1890, F. H. Newell, Washington, 1894, p. 222.

[2] Annual Report of the Commissioner of the General Land Office for the fiscal year ending June 30, 1894, pp. 288, 304, 321.

Lands disposed of in Western public-land States.

States and Territories.	Railroad.	Grant and swamp.	Private and miscellaneous.	Total disposed of.	
				Acres.	Square miles.
	Acres.	*Acres.*	*Acres.*		
Arizona	1,751,401	.....	2,494,408	4,245,809	6,634
California	6,464,235	10,531,852	19,128,525	36,124,612	56,445
Colorado	638,924	1,404,000	17,223,549	19,266,473	30,104
Idaho	160,609	.....	3,492,613	3,653,222	5,708
Kansas	7,703,465	.....	43,758,742	51,462,207	80,410
Montana	5,027,280	.....	5,338,087	10,365,367	16,196
Nebraska	7,258,298	.....	30,730,972	37,989,270	59,358
Nevada	551,647	.....	1,948,353	2,500,000	3,906
New Mexico	1,438,485	14,181,000	3,380,515	19,000,000	29,688
North Dakota	6,603,060	.....	12,704,853	19,307,913	30,169
Oklahoma	.....	.....	7,873,118	7,873,118	12,302
Oregon	2,667,401	217,998	15,406,410	18,291,809	28,581
South Dakota	.....	.....	22,844,814	22,844,814	35,695
Utah	747,124	.....	4,252,876	5,000,000	7,812
Washington	7,848,576	.....	8,956,191	16,804,767	26,257
Wyoming	758,125	.....	3,114,783	3,872,908	6,051
Total	49,618,630	26,334,850	202,648,809	278,602,289	435,316

Railroad lands.—The first column of the table, under the heading "Railroad," includes both the amount already patented to the railroad corporations and the area selected but to which the title has not yet been confirmed. These figures by no means represent the total extent of the grants by Congress to the various transcontinental lines. As shown by the general map, Pl. XXXV, these railroad lands extend in broad belts across the country, including some of the most valuable areas within the States traversed. The most northerly of these is the Northern Pacific. This grant, dated July 2, 1864, designated the line of the road as extending westerly by the most eligible route from a point on Lake Superior, in Minnesota or Wisconsin, to a point at or near Portland, Oregon. The odd sections, to the amount of 10 sections per mile on each side of the road in the States and 20 sections on each side of the road in the Territories, were granted. In case, however, title to these designated sections could not be given to the corporation, it was allowed to select an equivalent amount of land lying within 30 miles of the road in the States and within 50 miles in the Territories. On the map the grant lands are not shown east of the State of North Dakota, but to the west of the Red River they are indicated in a general way by crosshatching, covering an area 80 miles in width, within which every alternate section belongs to the railroad company or will ultimately become its property. The indemnity limits extending outside of this are not given.

Stretching across the central part of the country are the grant lands of the Union Pacific and of the Central Pacific Railroad companies, the first extending westerly from the Missouri River to Ogden, Utah, and the second from Ogden west to San Francisco. The original grant to the Union Pacific Railroad Company was dated July 1, 1862. It provided for the construction of a railroad from the western boundary of Iowa to a point on the one hundredth meridian within or

between the valleys of the Republican and Platte rivers, and from this point westesly to the western boundary of Nevada. Subsequent legislation granted the odd sections within 20 miles on each side of the road, but gave no indemnity limits. Branch lines were also provided for by subsequent grants to the same corporation or other companies which have later become parts of the Union Pacific system. The location of the alternate sections thus granted is shown on the map by the cross-lined portions in Nebraska, Wyoming, Colorado, and Kansas.

The most southerly grant is that to the Atlantic and Pacific Railroad Company, extending from a point near Albuquerque, N. Mex., westerly across Arizona. This was originally dated July 27, 1866, and called for the construction of a road from the States of Missouri and Arkansas to the Pacific Coast. Grants were made to this company of odd sections to the amount of 20 sections per mile on each side of the road through the Territories. By subsequent action, resulting from failure to complete this road through Indian Territory and eastern New Mexico, the grant was reduced to the limits above mentioned. The grants within the States of Missouri and Arkansas, as well as those of the other Eastern public-land States, are not shown upon the map, as upon this scale such representation would be confusing.

Extending in a general northerly-and-southerly direction through California and Oregon are the land grants of the Central or Southern Pacific Railroad. These have been represented upon the map as nearly as possible, although many important questions are still in dispute, and the exact extent and location of the railroad-grant lands can not be definitely known. The band upon the map indicates the belt of country 20 miles wide on each side of the road within which each odd-numbered section has been granted to this company. The indemnity limits, extending 30 miles on each side, are not shown. The Southern Pacific system includes the original grant to the Central Pacific, above mentioned, of odd sections within 20 miles on each side of the road extending from Ogden, Utah, to San Francisco, Cal., this possessing, however, no indemnity limits.

Within the State of Oregon are shown on the map three narrow bands indicating the location of lands granted for the construction of various wagon roads. The most northerly of these is that from The Dalles, in Oregon, to Fort Boise. The original grant was dated February 25, 1867, and donated the odd sections for 3 miles in width on each side of the road, with indemnity limits extending to the odd sections within 10 miles of the road. Immediately south of this is the road from Albany, Oregon, to the eastern boundary of the State, this embracing 3 sections per mile to be selected within the limits of 6 miles on each side of the road. The third notable wagon-road grant is that from Eugene, Oregon, to the eastern boundary of the State, including odd sections for 3 miles in width on each side of the road, without indemnity limits. There are a number of shorter wagon-road grants within this State extending from the valleys west of the Cascade Range to the coast.

The figures above given do not by any means indicate the total amount of land which will ultimately be patented to the railroad corporations or their representatives, but merely the amount which has already been selected and patented. There are still many millions of acres embraced within the grant limits which, although reserved on the books of the General Land Office, have not as yet been selected by the railroads. For purposes of taxation these lands are considered as public lands until taken by the railroad companies, and therefore, to avoid payment of taxes and other liabilities, it is apparently the custom of the railroad corporations to neglect to make selections until the land is disposed of or is of immediate use. So far as can be ascertained, no estimate has yet been made of the probable amount of these transcontinental railroad-grant lands, and there is considerable uncertainty regarding the status of large tracts, owing to unsettled questions as to whether portions of large donations have not been forfeited.

Grant and swamp lands.—Under this heading is included the estimated acreage within each of the public-land States claimed by individuals under the old Spanish grants or selected by the State under the swamp-land act. The greater part of this is within California, Colorado, and New Mexico, where the Spanish grants, aggregating many millions of acres, comprise some of the choicest lands. The principal area of so-called swamp lands is in the State of Oregon, where, under the construction of this act, a considerable extent of fertile land has been patented to the State. The figures do not include the amount selected, as it is improbable that all of this will be thus given away.

Private and miscellaneous entries.—The third column of figures in the table includes by far the greater portion of the land disposed of, and is intended to represent the amount which has been sold or patented under the preemption, homestead, desert, timber-culture, and similar acts. At this time it is not practicable to separate these different methods of disposing of the land, but from an inspection of the figures it appears that by far the greater portion of the land has been taken up under the homestead act, although many of the entries were later commuted for cash.

LANDS RESERVED.

The table on page 478 gives as the area reserved in the Western States 162,134 square miles, this being a little over 10 per cent of the aggregate extent of the Western States and Territories. This amount is made up principally of the Indian reservations, next in importance coming the large tracts reserved for the purpose of protecting the forests. To this have been added the military reservations. There are, in addition, tracts withheld from entry by various special acts of Congress or by decisions of the General Land Office. These, however, in the aggregate are relatively small and need not be considered in this connection.

Indian reservations.—The data as to the location and extent of the Indian reservations have been taken from the annual report of the Commissioner of Indian Affairs.[1] In this volume is given the area of each reservation in acres and in square miles, together with the name of the tribe occupying it. These areas are given by States and Territories in the following table, adjustment being made where a reservation extends across State lines. Besides the reservations embraced within the Western public-land States, given in the table on page 466 (including the military reservations), and in detail on page 492, there are others in the eastern half of the country aggregating 2,832,512 acres, or 4,426 square miles. This amount is made up as follows: Iowa, 2,900 acres; Michigan, 5,944; Minnesota, 2,243,753; New York, 87,677; North Carolina, 65,211; Wisconsin, 427,027. The lands reserved for Indian purposes in the West (82,708,797 acres) are being steadily diminished year by year, the lands being in many cases allotted in severalty to the Indians and the balance thrown open to settlement by the whites. A few years ago the Indian reservations appeared as extensive tracts covering a large part of the map of the United States, but now some of them can hardly be found, so greatly have their areas been reduced.

Forest reservations.—The reservation of land for the purpose of forest protection is a novel procedure in the administration of public lands, being somewhat in the nature of an experiment. The law under which these forest reservations are proclaimed by the President was approved on March 3, 1891, and since that time seventeen reservations have been proclaimed, having an aggregate area of 17,564,800 acres,[2] or 27,445 square miles. These reservations, as shown by the map, Pl. XXXV, are within the States of California, Colorado, Oregon, Washington, and Wyoming, and the Territory of Arizona. With these is here included the Yellowstone National Park (1,920,000 acres, mainly in Wyoming), which, although reserved as a park, can in effect be classified most nearly with these forest reservations. No reservation of this character has been made by the National Government in the eastern part of the United States, but comparable to these forest reservations are the great State parks instituted by New York. It is probable that in order to protect the water supply of densely populated areas many of the older States will be compelled to purchase and hold considerable tracts of rough or mountainous land, unfit for agriculture. These lands, if protected from fire, and, if necessary, supplied with desirable kinds of trees, will be of value, not only as furnishing unpolluted waters, but as supplying timber as rapidly as the trees reach maturity.

Military reservations.—The lands now held for military purposes are enumerated in the annual reports of the Commissioner of the General Land Office. In the volume for 1894 these are given on pages 247–255.

[1] Report of the Commissioner of Indian Affairs, 1894, pp. 484–498.

[2] Report of the Commissioner of the General Land Office, 1894, p. 43[illegible].

According to this statement, the total extent is 1,597,933 acres, or 2,497 square miles. Of this amount, nearly the entire extent is in the Western public-land States, 26,019 acres only being in the the eastern part of the country. Of this, about 14,000 acres are in Florida, the remainder being included within the States of Alabama, Arkansas, Illinois, Louisiana, Michigan, Minnesota, Missouri, and Wisconsin. These military reservations are being abandoned from time to time, and although not at present open to settlement, yet they might be considered as part of the vacant public lands.

Reservations in Western States.

States and Territories.	Indian.	Forest.	Military.	Total.	
	Acres.	*Acres.*	*Acres.*	*Acres.*	*Sq. miles.*
Arizona	*a* 11, 051, 597	1, 851, 520	139, 149	13, 042. 266	20, 378
California	438, 868	5, 438, 720	87, 469	5, 965, 057	9, 320
Colorado	1, 094, 400	3, 103, 360	30, 720	4, 228, 480	6, 607
Idaho	*b* 2, 225, 051	.....	3, 796	2. 228, 847	3, 483
Indian Territory	19, 840, 000	.....	.....	19, 840, 000	31, 000
Kansas	73, 796	.....	22, 649	96, 445	150
Montana	9, 382, 400	.....	253, 824	9, 636, 224	15, 057
Nebraska	127, 433	.....	61, 995	189, 428	296
Nevada	*b* 808. 215	.....	.....	808, 215	1, 263
New Mexico	*a* 4, 300, 085	311, 040	169, 492	4, 780, 617	7, 470
North Dakota	3, 812, 833	.....	625, 899	4, 438, 732	6, 936
Oklahoma	7, 208, 738	.....	32, 640	7, 241, 378	11, 315
Oregon	1, 803, 495	4, 653, 440	1, 945	6, 458, 880	10, 092
South Dakota	10, 168, 842	.....	39, 985	10, 208, 827	15, 951
Utah	*a* 4, 516, 480	.....	8, 148	4, 524, 628	7, 070
Washington	4, 046, 564	967, 680	19, 825	5, 034, 069	7, 866
Wyoming	1, 810, 000	*c* 3, 159, 040	74, 378	5, 043, 418	7, 880
Total acres	82, 708, 797	19, 484, 800	1, 571, 914	103, 765, 511	.....
Total square miles	129, 233	30, 445	2, 456	162, 134	162, 134

a The total area of the Navajo Indian Reservation is given in the report of the Commissioner of Indian Affairs for 1894 (p. 490) as 7,698,560 acres, and as being in the Territory of New Mexico. This reservation is, however, mainly in Arizona, and extends northward into Utah. An estimate of the amount of land in each Territory gives the following figures: Arizona, 4,651,560 acres; New Mexico, 2,503,000 acres; Utah, 544,000 acres; total, 7.698,560 acres. These figures have been added to the area of reservations in Utah and Arizona, respectively, as given in the report of the Commissioner of Indian Affairs, and corresponding deduction has been made from the total extent of Indian reservations in New Mexico.

b The Duck Valley Indian Reservation is given as being in Nevada, but nearly one-half of it extends northward into Idaho. An estimate of the amount in each State gives in Idaho 145,920 acres, and this amount has been transferred to that State, a corresponding reduction being made in the figures of Indian reservations in Nevada.

c This amount includes 1,920,000 acres, the estimated area of Yellowstone National Park. This is considered as being wholly within the State of Wyoming, although the northern and western edges extend into Montana and Idaho.

VACANT LANDS.

The total extent of vacant lands in the Western States, as shown on page 478, is 953,515 square miles, or 610,249,600 acres, this being 61.48 per cent of the entire land surface of the seventeen States and Territories included under this designation. The general character of these lands has been already described, and their location can be seen by reference to the map, Pl. XXXV. As shown on this map, there is in in no State any very considerable area relative to its size that does not contain small patches of land which has passed out of the hands of the General Government. The otherwise colorless portion of the map which represents the broad expanse of arid land is broken here and there with dots representing localities where, from the occurrence of water, farmers or cattle men have found it possible to make a home.

Probably the largest extent of territory which might be carved out, free from occupation or private ownership, is the tract beginning west of Great Salt Lake and extending westward across Nevada and southward to southern California and western Arizona, and including the greater part of the really desert areas of the United States. This is bounded on the north by the grant lands of the Central Pacific Railroad, and is crossed on the south by the Atlantic and Pacific Railroad lands, but neither of these railroads has made any considerable selec-

FIG. 52.—Diagram illustrating proportion of vacant lands, classified according to grazing, woodland, forest, and desert areas.

tions within these limits. The farms or ranches within this area are located at or near springs along the base of the mountains, and are at long distances from one another. The population is probably tending to diminish rather than to increase, owing to the lessened profits of cattle raising and decreasing demand for agricultural products.

The small map, Pl. XXXVI, exhibits in a broad way the relative proportion of grazing land, forest, and woodland. An estimate has been

prepared showing in round numbers the extent of lands of these classes now vacant, and also of the desert. This is comparable with the estimate shown on page 483, the latter, however, applying to the whole extent of the arid region, while this table relates only to the land now vacant and still owned by the General Government. It is, of course, impossible to arrive at any considerable degree of accuracy in such estimates, but the following figures are presented in order to bring clearly to mind the probable character of the unoccupied lands. The proportion of woodland and forest is notably large—greater than is generally supposed—but it must be borne in mind that on these areas the trees are very often very sparsely scattered, and that within the bounds considered as forest there are broad open spaces. The relative proportion of lands of these classes is shown on page 493 in diagram (fig. 52).

Vacant lands in the Western public-land States.

States and Territories.	Vacant.		Millions of acres.				
	Square miles.	Acres.	Grazing.	Wood.	Forest.	Desert.	Water supply.
Arizona	85,908	54,981,120	30	3	7	15	2
California	90,215	57,737,600	27	5	6	19	17
Colorado	66,934	42,837,760	30	7	6	0	8
Idaho	75,099	48,063,360	19	20	8	0	1.5
Montana	114,057	72,996,480	50	13	10	0	11
Nebraska	17,186	10,999,040	11	0	0	0	1.5
Nevada	104,571	66,925,440	42	5	0	20	2
New Mexico	85,302	54,593,280	45	8	2	0	4
North Dakota	33,090	21,177,600	21	0	0	0	2
Oklahoma	15,213	9,736,320	9	0	0	0	1
Oregon	55,887	35,767,680	17	11	9	0	3
South Dakota	25,204	16,130,560	15	0	1	0	5
Utah	67,308	43,077,120	16	11	6	10	4
Washington	32,757	20,964,480	6	5	10	0	3
Wyoming	83,644	53,532,160	36	8	5	5	9
Total	952,375	609,520,000	374	96	70	69	74

RATE OF DISPOSAL OF VACANT PUBLIC LANDS IN THE WESTERN STATES.

In order to exhibit the rate at which public lands are being disposed of, and to give some conception of the relation which the lands passing out of the hands of the General Government bear to the total amount still available, the table on page 496 has been prepared. This gives in square miles the average amount annually disposed of for the past five years. This quantity is compared with the total area of the State or Territory, and also with the total area now vacant. In nearly all cases the rate of disposal is less than 2 per cent per annum, the exceptions being in Oklahoma, where, owing to the throwing open of the Indian lands, there was an extraordinary increase of the number of entries. The average for all these sixteen States and Territories was almost exactly 1 per cent; in other words, at the rate of the last five years, an area equal to that of the whole of the sixteen Western States and Territories would be disposed of in one hundred years. In comparison with

the land now vacant, the rate of disposal has been 1.59 per cent, and if this rate should be maintained continuously until all of the lands had passed out of the hands of the National Government, it would require nearly sixty-three years to exhaust the present supply. As a matter of fact, however, as pointed out in the case of the Eastern public-land

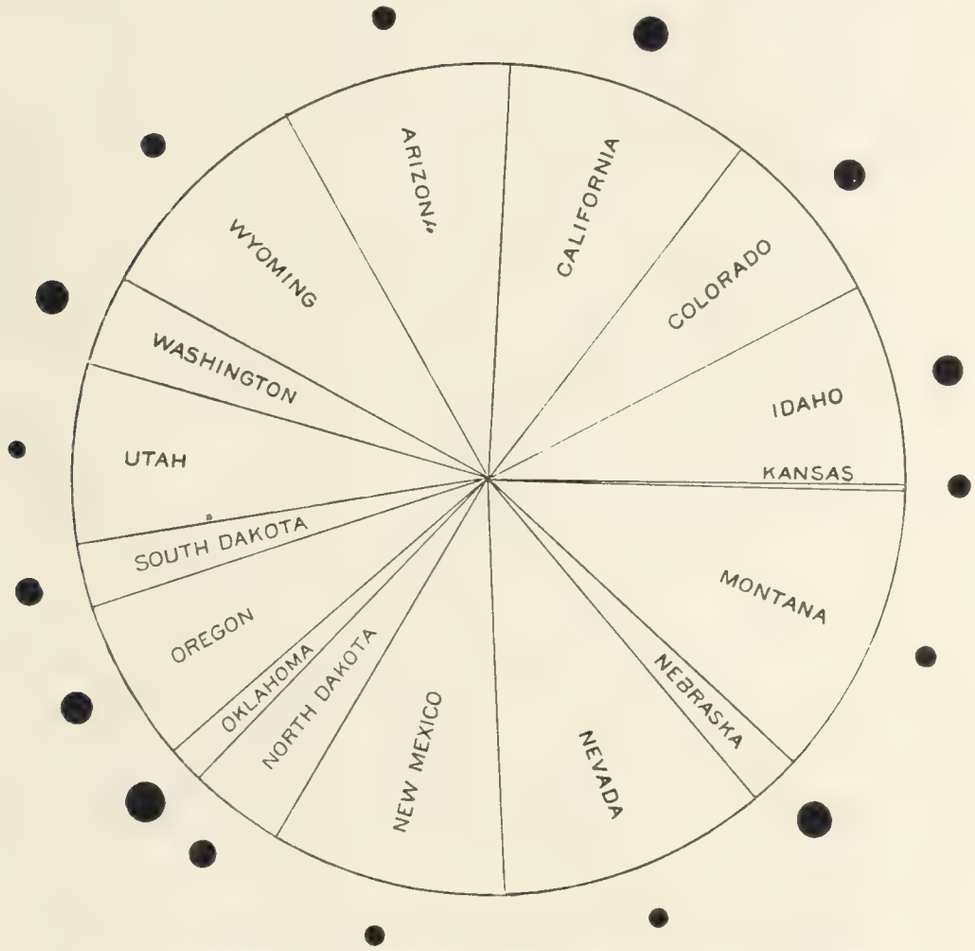


FIG. 53.—Diagram illustrating area of vacant public land and rate of disposal.

States, the rate of disposal is tending to decrease as the better lands are selected, so that this period would be indefinitely prolonged. A large part of this vacant land is also unsuitable for this private use, being desert in character, as has been shown, and under the present laws would remain forever in the possession of the National Government.

Rate of disposal of vacant public lands in the Western public-land States.

	Square miles.	Per cent of area of State.	Per cent of area vacant.
Arizona	544	.48	.63
California	1,556	1	1.72
Colorado	1,236	1.19	1.85
Idaho	486	.58	.65
Kansas	841	1.02	65.30
Montana	797	.55	1.68
Nebraska	1,612	.21	9.41
Nevada	131	.12	.13
New Mexico	501	.41	.59
North Dakota	858	1.22	2.59
Oklahoma	2,373	6.11	15.59
Oregon	1,075	1.13	1.84
South Dakota	1,200	1.56	4.76
Utah	325	.39	.48
Washington	1,254	1.88	3.83
Wyoming	513	.53	.59
Total	15,302	1.01	1.59

The rate of disposal is best exhibited by the diagram on page 495 (fig. 53). The large circle shows the total area of vacant land in the sixteen States and Territories, the segments being proportional to the land in each. The small dots around the edge exhibit the average amount of land being disposed of each year, and allow comparison with the total extent of the lands from which these disposals are made.

WATER SUPPLY.

SOURCES OF SUPPLY.

In the preceding pages has been given a general outline of the extent, location, and condition of the vacant public land and its relation to other portions of the country. It has been stated that the future utilization of this vacant land depends largely upon the water supply, and upon intelligent regulation thereof based upon a thorough knowledge of the resources of the country and its limitations in this regard. In the following pages it is purposed to give a brief statement of what is known of the available supply in each of the Western public-land States in which there are considerable areas vacant, and to indicate the lines of investigation now being carried on.

The sources of supply for the lands under discussion may be considered broadly under three heads—streams, wells, and stored water. By far the most important of these sources are the surface streams, since these furnish the greater part of the water and render valuable more than nine-tenths of the land now reclaimed by the artificial application of water. Wells, both artesian and of the ordinary form from which water is pumped, come second in importance, and reservoirs, or similar means of storing floods, come last, although in many instances of great value.

Streams.—In the discussion of streams as a source of water supply, it is convenient to distinguish between large and small, although there is, of course, no sharp line of demarcation between these. There are

very few really large rivers in the West, most of the streams containing a quantity of water so small that in humid regions the term "river" would not be used. The smaller streams—those commonly known as creeks—are fairly well distributed throughout the mountain region, and up to the present time have been of the first importance in the development of the country. The rivers carrying large volumes of water have not been sources of wealth in proportion to their size.

The smaller streams rising in the high ground descend with considerable fall, and the quantity of water throughout the larger part of the year being not greater than the capacity of a few ordinary irrigating ditches, it can be controlled by comparatively simple works. The steep grades of the stream beds make it possible for farmers or small communities to construct crude canals and carry the water far out upon the valley lands. On the other hand, the larger rivers, having usually less fall, except in narrow, rocky canyons, can not be controlled, nor can their waters be diverted without the most expensive construction. It is rarely possible for individuals, singly or in small groups, to dig ditches leading from these streams to the fertile soil, owing to the depth to which most of the rivers have excavated their channels below the adjacent flood plains or bench lands. The expense of construction and of maintenance increases geometrically as the size of the river increases, until, under pioneer conditions, with small resources beyond manual labor, and with uncertain future, it becomes almost impossible for settlers to introduce agriculture upon the fertile lands bordering the larger rivers. Thus it is that the greater part of the public domain in the Western States which has been taken up by individuals is along or near the small mountain streams, and developments have not proceeded rapidly along the larger rivers except upon the lower, humid plains. One reason for this is that throughout the great central portion of the Western States many of the important rivers have cut deep canyons and flow in narrow gorges; but even where the topographic conditions are such that water might be taken out, the enormous expenditure necessary has been prohibitory.

The reclamation of the arid lands has been accomplished mainly by individual effort in the construction of small ditches. Wherever it has been possible for a farmer, or several farmers acting in unison, to construct irrigation works by their own labor and without the use of capital, this has been done. The average cost of these ditches and small canals, as given by their owners, has been small, owing to the fact that the farmers have not placed a high valuation upon their own labor, nor have they kept account of the many efforts and failures. All of the time which could be taken from other work has been put upon the ditch, and in most cases many renewals or extensions or relocations have been effected. The building of these has generally been more or less experimental, a line being plowed or dug out, and modified, especially at its upper end, as circumstances required. This

is perfectly feasible with small streams of water, but in the case of large rivers and of undertakings of considerable magnitude there can not safely be anything in the nature of an experiment, for if the first trial does not succeed, it is rarely possible to raise sufficient funds to reconstruct or modify the original design.

Nearly all of the opportunities for the development of small irrigation works have already been utilized or appropriated by individuals, but there remain many opportunities for development upon lines which will require for proper construction the use of large sums of money, such as can be procured only by great corporations, or by the State or National Government. The smaller projects, however, have been usually built without system, and even without any general plan, so that the future development of larger and more comprehensive undertakings is often blocked or rendered impossible by the network of little ditches. It may be possible in some localities to acquire and extinguish these vested rights, but the cost of such proceedings would be a further burden to be added to the expense of overcoming the natural difficulties, and one which must ultimately be borne by the farming population.

It is a fact now generally recognized that any considerable extension of the area irrigated from streams can come only through the successful operation of large enterprises. These, however, have not been favored by popular sentiment nor by legislation, there being a prevalent feeling that the corporations controlling the necessary funds and conducting operations on a large scale may prove a menace. The land laws have been so framed that it is impossible for large associations to obtain legally title to tracts of such size that the sale of these will repay the cost and risk of building a great canal. There are exceptions to this in the cases of the old Spanish grants and of donations to railroad corporations, where it has been possible for investors to acquire considerable areas lying adjacent to one another, and here some of the largest irrigation projects of the country have been successfully undertaken. The conditions of acquiring ownership to the great bulk of the public lands now vacant, however, are such that it is impracticable to attempt to secure title to contiguous areas, and without such title to the land to be reclaimed it is doubtful whether any large canal can be profitably built; for experience has shown that the only safe investment in this line is where the expense of construction is repaid out of the increased value of the land, rather than by the sale of water rights or by annual rentals. The price of these water rights, and the amount which can be charged each year for the privilege of taking water through a large system, are in most States under the control of the legislature or of county officials, so that corporations in this respect are at the mercy of the people rather than the reverse.

It appears, therefore, from a study of the conditions, that no great developments can take place except through State or Government inter-

vention, or through such changes in the land laws as will permit persons undertaking great enterprises to obtain ownership of the lands to be benefited and secure to themselves the increment of value under reasonable restrictions. Under present conditions, should a great project involving the public lands be broached, the lands in question are liable to be filed upon at once by speculators eager to obtain the unearned increment due to the enterprise of others. As a result the farmer who ultimately buys and cultivates the land must not only refund, in one way or another, the original cost of the project, but must do this in addition to paying an increased valuation due to speculation. If the land is worth $1.25 per acre, the Government price, the prospective canal may cause this to increase, say, eight times, or to $10 per acre. The speculator, learning of the project, can, under present laws, rush in and file upon a homestead, and, if fortunate, secure this profit with comparatively little risk or expense to himself. The farmer must ultimately pay this advance, which equitably should have gone to reimburse the outlay for reclamation. In other words, under present circumstances, the farmer is called upon to pay a double cost for reclamation, when under possible theoretical conditions the increase in value of the lands over their sterile condition should have done this.

The rivers of the Western public-land States from which water is obtained for use upon the land may be considered under seven great groups. These are, first and most important, those ultimately tributary to the Mississippi River, including all of the streams east of the Rocky Mountains from the headwaters of the Missouri southward through the basin of the Platte and Arkansas. South of this is the second system, those streams tributary to rivers flowing directly into the Gulf of Mexico, the Rio Grande being the most important, although not the largest. To the west and interlocking with these are the rivers of the Colorado drainage, characterized by the great canyons and gigantic gorges through which many of them flow. Beyond these is the great Interior Basin, comprising groups of rivers which do not flow into others, but which are lost imperceptibly in the sands of the desert areas, or which flow into some salt or brackish lake from which the waters are finally evaporated. In the northwest is the Columbia drainage; and in California the Sacramento and San Joaquin, draining the western slope of the Sierra Nevadas. The last group includes the streams, usually of insignificant length, draining the Coast Ranges and flowing directly into the Pacific Ocean.

Wells.—Although by far the greater part of the acreage of the lands made valuable by the artificial application of water is dependent upon streams, yet wells play a very important part as sources of prosperity. These may be divided into two classes—the artesian or flowing wells, and those from which water must be pumped or lifted by various devices. The flowing wells are local phenomena, and, although attracting popular attention by their novelty, are not worthy of consideration

to the exclusion of the ordinary form of well. In many of the older countries wells have been employed in irrigation since the beginning of historic records, and water has been lifted considerable distances to be applied to growing crops. It is, however, only within a few years that the practicability of utilizing any notable extent of the public domain through this agency has received general recognition. It is true that market gardeners have used windmills and other devices from time immemorial, but that this insignificant method of irrigation would ever be of public importance has been almost entirely overlooked.

Experience in various parts of the country has shown that a farmer who will content himself with a few acres and utilize his resources to the best advantage can make a good home and living upon the arid or semiarid lands by means of agriculture rendered possible by water pumped from a well. The greatest progress in this line has been in subhumid States, including the broad belt from the James River Valley of the Dakotas southward through western Nebraska and western Kansas. There a relatively large population was almost without means of support, owing to the occasional or periodic droughts. After many experiments and failures it was found that continued success was obtained mainly by those who practiced irrigation, this being possible in many localities only by means of well water. Attention being drawn to this fact, systematic endeavors have been made to perfect methods and apparatus, until at the present time large numbers of men are employed in sinking wells and in erecting suitable machinery for bringing the water to the surface and storing it for use as required. There is every reason to believe that continued prosperity will follow the development of small farming in this manner, especially when combined with stock raising, upon the broad grazing lands of the West.

The location of the successful wells, the geologic structure which renders these possible, the quantity of water which can be obtained, and similar facts are the subjects of investigation by this Survey, and the results are being published from time to time. Particular attention is called to the paper in this report by Prof. Robert Hay, relating to portions of western Kansas, eastern Colorado, and adjacent areas in Nebraska. It has been found that, although there are many localities where water can not be obtained in profitable quantities or where it is unfitted for use, yet a thorough search will disclose many places where it is highly probable that a good supply can be had at moderate depth. Endeavor should be made to point out these places as soon as possible and to lay the information before the public as a guide in development. The occurrence is governed by geologic structure, and a thorough knowledge of this, as well as of related facts, is essential before the subject can be said to be well known.

The amount of water which can be obtained from any one well is not usually sufficient to irrigate more than a few acres—from 2 to 10, or possibly more if a storage reservoir is used. This limitation of supply

is in many respects a boon, as the farmer is forced to concentrate his efforts upon smaller areas, and should produce larger results. One of the greatest detriments to the realization of the highest type of cultivation and of civilization upon the public domain has been the attempt by the farmer to cultivate enormous areas and to own everything to which he can possibly lay claim. Where water is obtained from a well, it is necessary to utilize the ground to its fullest extent in that immediate vicinity. As a result, the homes created by this means will tend to cluster in small settlements where the water is available, leaving the broad grazing lands of the semiarid States untouched by the feeble attempts at cultivation.

The cost of obtaining water in this way can not yet be stated, as applying to the country as a whole, for wide information must be collected and brought together, and in many parts of the West the matter is still in an experimental stage. The success attained, however, is such that it is obvious that the cost, though greater than that of the ordinary small irrigation ditch, is by no means prohibitory. This cost is decreasing year by year as in each locality knowledge is obtained of the best methods, and machinery and appliances are devised to meet particular needs. The principal agency employed in pumping water is the wind, but next to this in importance are the various engines employing either steam or gasoline. The gasoline motor is apparently growing in favor, and is being widely used on account of the convenience and ease with which it is operated. Wind power, although often unreliable, is considered the cheapest and is the most widely employed. The water is usually pumped first into small reservoirs constructed on the surface of the ground and from 100 to 200 feet across. Here the temperature of the water generally rises, and it is rendered more fit for application to the plants by exposure to light and air. These reservoirs are often bordered by trees, and serve not only as refreshing and beautifying spots near the home, but become a source of value through the raising of fish.

Artesian wells have attracted considerable attention, but they are probably of less real value than the wells from which water must be pumped. One reason for this lies in their very convenience. Water flowing at all times is cheaply regarded; it is allowed to run to waste, forming swamp places, or is applied too lavishly to the fields. When this water contains, as it often does, any notable per cent of salts, extravagant use injures the soil and results in discouragement to the farmer; so that actually slower progress has been made with these artesian wells than where the conditions are less favorable. The regions within which these occur are being examined with a view to ascertaining the source of this water, its quantity, the extent to which wells can be increased in number, and their probable utilization in various ways. In some places, notably in the Dakotas, the pressure of water from these wells is sufficiently great to be of value in running light machinery; and thus the wells have an interest to others besides the farmer.

The artesian wells of the country as a rule gradually decrease in amount of water delivered and in pressure, although there are many exceptions. This decrease is due not so much to drawing down the hydrostatic head or the reserve store of water, as to mechanical defects in construction or accidental injuries. In many instances the first wells were improperly cased, or even were not cased at all, resulting in leakage from one stratum to another, or in the falling in of the walls. The force of the water, also, is so great that sand is carried to the well, and, accumulating, often clogs it, so that constant care is required in order to preserve the flow of water. Thus it is that after the first few years an artesian well may be a constant source of expense and annoyance, due to many causes, some of which have not been ascertained.

Reservoirs.—There are many parts of the country where it will be impossible to obtain water from perennial streams or from wells, and yet where, as in southern California, the fertile soil and genial climate render possible the cultivation of high-grade, expensive crops. In such instances it is occasionally possible to construct storage reservoirs in which to hold the flood waters of the intermittent streams characteristic of much of the arid region. In other localities, where the development has proceeded to such an extent that all of the ordinary flow of the streams is utilized, attempts are being made to save the excess waters of the spring or of unusual showers, in order that these may be employed to supplement and increase the ordinary supply.

There are also many places, especially within the mountain region and among the foothills, where, with comparatively small expense, dams can be built, closing the outlets to nearly level valleys or small parks, in which great quantities of water could be held each year. From time to time some of these are utilized, but the expense of construction and the difficulties of bringing the stored water from the reservoir and securing control of it have prevented general work along this line.

In the case of the public lands, one of the great obstacles to the utilization of storage reservoirs is the lack of safeguards for water rights. For example, if water is saved in a reservoir high among the mountains by one person or company, for the purpose of employing it upon lands 50 miles or more away, it usually happens that this water must be allowed to flow down natural channels, and possibly by the heads of many small ditches having prior rights to the use of the stream. Theoretically it should be possible to let this pass through the natural channel and recover it below, but in most localities this is practically impossible, owing to the fact that the owners of the various ditches will inevitably capture some of this water during the dry season, or claim it as part of the regular flow of the stream. Unless, therefore, the stored water belongs to the community as a whole, or to ditch owners having priorities to the use of the stream, it appears impracticable to attempt to store water at great distances from the land to be

RESERVOIR SITE AT HUSTON FLAT, IN SOUTHERN CALIFORNIA.

irrigated. This has led to the construction of many low-lying reservoirs, upon the edges of the valleys or out upon the plains, convenient to the land to be irrigated, where they are filled at time of flood or during winter. This method, however, is not economical, as the losses from evaporation are great, and it is often impracticable to fill the reservoirs at proper times.

The Geological Survey has been authorized to reserve suitable sites for reservoirs upon the public lands, and it has found and designated a considerable number of these. But, owing to the imperfect condition of the land laws, and to the general indifference or the fear of interference with private speculation, little public support has been given to the measure. Careful provision for future public needs is not looked upon with favor nor warmly supported when it might interfere with immediate private gain, and in this matter, as in the case of the forests of the country, it is probable that the importance of the subject will not be generally recognized until the available natural wealth has been more nearly converted to private use.

The storage of water, except under the most favorable conditions, is one of the class of undertakings which have not been financially successful. The enormous first cost involved in making a perfectly safe structure, or the destructive and disastrous results following imperfect construction, have deterred possible investors. There is probably no construction involving greater menace to life and property than an insecure dam situated on the main drainage lines and above settlements and habitations. Especially is this the case in the West, where storms of extraordinary violence, or "cloud-bursts," are apt to occur at almost any time of the year. Yet with the progress of settlement it will be necessary to build reservoirs, and due provision must be made for building them under proper supervision and with every regard to permanence and safety. In previous publications of this Survey description has been given of various classes of dams—earth, timber, and masonry—with a full discussion of the cost and character of many already completed and of others designed.[1] It is therefore unnecessary to discuss this matter at length. At present, however, the attitude of investors, especially in the public-land States, where it is difficult to procure ample capital, is toward extreme economy in construction. There is an unwillingness to pay out large sums either for engineering skill or for thoroughness of work, due chiefly to the desire to obtain immediate returns through rapid construction and quick sale of the property. As a result, many of the dams already built are open to severe criticism, and progress in this line has been discouraged.

In any particular case it is generally obvious which of the sources of water supply can be utilized; but there are some cases in which there is room for debate or for critical examination by the expert.

[1] Thirteenth Annual Report of the United States Geological Survey, Part III. Irrigation. American Irrigation Engineering, by Herbert M. Wilson.

Throughout a great part of the country, however, it will be found practicable to cultivate some of the rich soils and to utilize the various resources through the employment of water obtained in one of these three ways. But in nearly every case recourse must be had to exact information, either as to the fluctuations of the stream, the structure of the water bearing rocks, or the probability of securing flood water at regular intervals, and of obtaining suitable materials for the construction of storage dams. A thorough study of all these points is therefore necessary as a prerequisite to the utilization of the remaining public lands. The investigation of matters pertaining to the hydrography of the country, especially as these relate to the geology, is now well under way, and, although far from complete, the information is being utilized with beneficial results.

ARIZONA.

This Territory is fourth among the political divisions containing vacant public land. Its total land area is 112,920 square miles (p. 478), or 72,268,800 acres. Of this land a little over 11,000,000 acres (p. 492) are included in Indian reservations, chief among which, and comprising considerable areas of good agricultural land, are those of the Navajo, Moqui, White Mountain, and Hualpai Indians. Although there are estimated to be 10,000,000 acres of forest, besides 8,700,000 acres (p. 482) of woodland, in this Territory, only one tract has been set aside. This is situated in Coconino County and is known as the Grand Canyon Forest Reserve. It was created by proclamation of February 20, 1893, and is estimated to comprise 1,851,520 acres. It is quadrangular in form, and embraces land on both sides of the Colorado River, being so located as to include points of peculiar interest and grandeur. The estimated area of vacant land disposed of, according to the Report of the General Land Office for 1894 (p. 165), is 4,245,809 acres. Of this amount about 1,751,401 acres have been selected or patented under grants to railroads.

The selections made under the railroad land grants have been mainly along the Little Colorado River and in the forest area south of the Navajo and Moqui reservations. The homestead and desert entries have been to a large extent in the valley of the Salt and Gila rivers, others being widely scattered throughout the eastern and southeastern portions of the Territory. The greatest body of untouched land is south of the Gila River, adjoining the Republic of Mexico, this being almost, if not quite, desert in character. To the north of the Colorado River, on the high, deeply eroded uplands, there are also vast stretches of public lands, as yet unsurveyed and apparently worthless except for grazing purposes. Only about one-fifth of the total area of the Territory has been surveyed and subdivided in the conventional manner into townships, ranges, and sections.

As shown by the map, settlement has been confined almost exclusively to the open valleys of the Gila River and its tributaries and to the higher lands in the vicinity of Prescott. This Territory is among the most arid of all the political divisions of the Union, and the difficulties of obtaining water are most pronounced. In the valleys among the mountains or on the high plateaus a little agriculture is successfully carried on without irrigation, but this is the exception rather than the rule. The greater part of the agricultural development has been in the Salt River Valley at points where water has been diverted from Salt River, and also lower down in the Gila Valley.

The principal available water supply of the Territory is from Gila River, and especially from its largest branch—Salt River. This stream and its tributary, the Verde, have been measured at various points, and computations have been made of the discharge at the Arizona Canal Company's dam, about 30 miles above Phœnix, the figures being given in preceding annual reports of this Survey. A considerable number of canals and ditches have been constructed, taking water from the Salt and Verde, as well as from the Gila itself; and the ordinary summer flow is needed for the lands now under cultivation. There is, however, an enormous amount of water going to waste at various times of the year, following the sudden storms or "cloud-bursts" in the mountains, but these floods occur at such irregular intervals and come with such violence that it is impracticable to attempt to save much of the water. There are a number of localities high among the mountains—notably, one in Tonto Basin—where dams could be built at a cost not excessive as compared with that of similar structures elsewhere.

With the exception of the great Colorado River, which, however, flows in stupendous canyons or gorges thousands of feet below the arable lands, the streams of the Territory are small, and usually intermittent. The Little Colorado and its numerous tributaries up in the plateau and on the Mogollon mesa furnish a supply for small ditches, the principal of these being in the vicinity of Taylor, St. John, and Holbrook, in Apache County. In the extreme southern part of the country, adjacent to the Republic of Mexico, are a number of streams, notably the Santa Cruz and the Sonoita, but the waters of these are claimed for lands now in private ownership, and the supply is far from sufficient for the valleys in which they flow.

There are few notable wells in Arizona, and none which are known to be flowing. Most of the deep wells are put down for the purpose of furnishing water for stock or for railroad purposes, and their supply is thus wholly utilized. Explorations have not been carried on with a sufficient degree of thoroughness to determine whether it may not be possible to obtain larger quantities of water in some of the important valleys. In various portions of the Territory are enormous tracts where the grazing at one time or another is good, but where herds can not be kept owing to the present impossibility of obtaining drinking water. Many attempts have been made to sink wells at various

points, but either on account of the expense involved or for lack of knowledge as to what might be expected, most of these have been abandoned as unsuccessful. On the lower valley lands along the Gila, especially where irrigation has raised the ground water, ordinary wells obtain a sufficient supply for stock purposes, and by means of windmills small areas are watered.

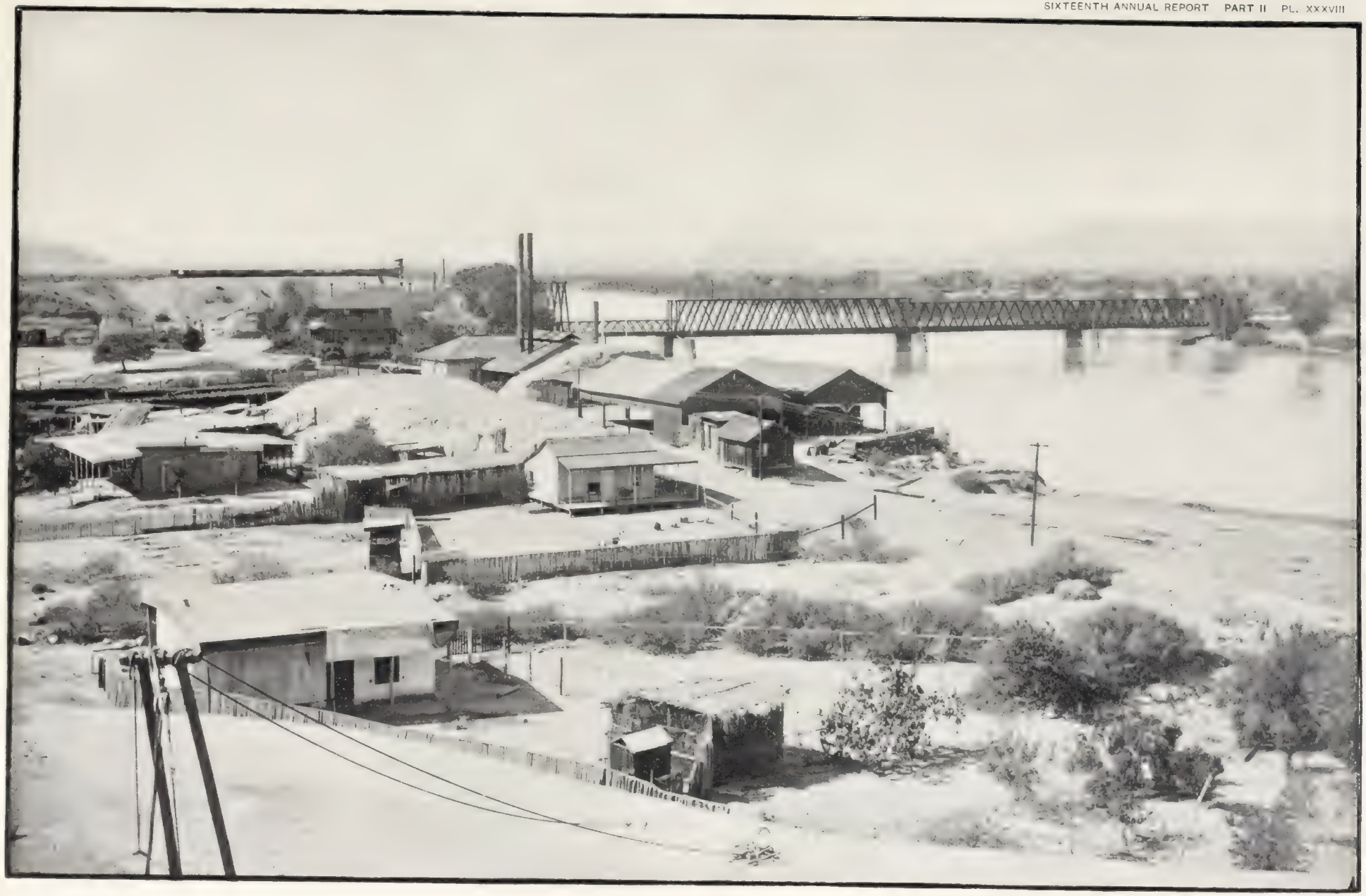
Storage reservoirs have been built in several places in the Territory, principally, however, for the purpose of hydraulic mining. One reservoir—that on the Hassayampa above Walnut Grove—was destroyed, with some loss of life and considerable damage to property, resulting in discouragement to this class of enterprise.

The total water supply of the Territory which can be rendered available for use at reasonable expense is estimated to be sufficient for about 2,000,000 acres of land. This estimate is not made with any claim to accuracy, being based on numerous assumptions and upon scattered measurements. It illustrates, however, the fact that the supply is far less than the demands of the area which has now passed out of the hands of the General Government, and is almost insignificant in comparison with the lands now vacant and needing water. It is, however, fairly well distributed, and it is possible that by developing every known source—springs, streams, wells, and storage reservoirs—homes can be made for many thousands of families and the greater part of the grazing lands can be utilized to far better advantage than at present.

CALIFORNIA.

This great State—the largest among the Western public-land States and Territories—embraces such a wide range of topographic conditions that a discussion of the water supply must be of the most general character. Although the greatest progress has been made here, both in the development of agriculture and in the utilization of the lands, there still remains over 90,000 square miles (p. 478) of vacant public land, or over one-half the area of the State. The greater part of this land is in the southeastern portion of the State, including the great Colorado Desert, Death Valley, and similar barren regions; from here a strip extends northward along the eastern boundary to the lava-covered plateaus in the northern part of the State. There are also vast stretches of vacant land along the northern Coast Ranges west and northwest of Mount Shasta. Much of this latter area, and also the vacant lands along the Sierra Nevada, are forested and have considerable value in timber.

California as a whole is estimated to contain 18,000,000 acres of forest, 27,000,000 acres of woodland, and over 42,000,000 acres (p. 482) of open land, mainly valuable for grazing. Of the part now vacant and open, when surveyed, for entry and settlement (p. 494), there are estimated to be about 6,000,000 acres of valuable forest, 5,000,000 acres of woodland, 27,000,000 acres of grazing lands, and 19,000,000 acres of actual desert, including in the latter some tracts which after a rainy season may furnish a little forage.



COLORADO RIVER AT YUMA, ARIZONA.

The forest reservations in this State are comparatively large, embracing in the aggregate over 5,000,000 acres (p. 492), or less than a third of the land originally covered with heavy trees. The principal area thus set apart is known as the Sierra Forest Reserve, and embraces over 4,000,000 acres, extending along the mountains from the Yosemite National Park southeastward to the vicinity of Bakersfield. The Indian reservations are relatively small, having been cut down from time to time, and are now of such proportions that even when the lands are allotted in severalty and the balance thrown open there will be comparatively small increase in the area of public land.

The railroad-grant lands are an important feature in this State, since they cover large portions of the fertile valleys. It appears that over 6,000,000 acres have already been patented to the railroads or selected by them, and there remain many million acres more reserved or held pending decision as to the rights of the corporations. In the southern part of the State especially the old Mexican land grants are also notable, since these were laid out in such a way as to include the more desirable portions of the country. In some cases they have been a detriment, retarding settlement, and in other cases the ownership of large tracts has enabled private enterprise to construct works upon a scale which would not have been attempted upon public land.

The water supply of the State is relatively large and well distributed. In the northern part, along the ocean, the climate is humid, and although there is a deficiency of summer precipitation, yet it is possible to raise large crops without the artificial application of water. The aridity increases, however, toward the south, and, as previously stated, in the southeastern part of the State, beyond the mountains, deserts abound. A large amount of accurate information regarding the rivers of the State, especially those of the San Joaquin Valley, has been obtained and published by the State engineer, and this material has been supplemented by the field work of this Survey. It is, of course, impracticable to discuss the character of even the more important rivers in a few paragraphs, but the following brief statements will convey a few general impressions:

In the Sacramento Valley, where irrigation is not absolutely necessary but is often of benefit, there is as a rule a large perennial supply of water coming from the mountains on both sides. Along the eastern foothills many ditches have been constructed, originally for hydraulic-mining purposes, but later used for agriculture. In the San Joaquin Valley the water supply from the Sierra Nevada on the east is generally large and well distributed, but on the western side of the valley there are but few streams, and these are mainly intermittent in character. Cereals can be cultivated in this valley without irrigation, even as far south as Kern County, but it has been found more profitable to subdivide the great farms and introduce the cultivation of high-grade crops on small areas.

Beyond the range to the east of the San Joaquin Valley is the narrow valley drained by Owens River, and to the south are the broad interior lands of the Mohave Desert. Here the water supply is scanty, and is obtained mainly from small streams heading in the short, steep slopes of the Sierra Nevada or among the irregular mountain masses lying to the southward, near the coast. Fig. 54 gives a view of Owens River and shows the character of this stream, the most important one in this part of the State.

The numerous ranges skirting or adjacent to the coast furnish a considerable supply of water to the valleys on the western sides, but the streams flowing toward the east and north into the desert are small and intermittent, no living stream reaching beyond the foot-

FIG. 54.—Owens River, east of Big Pine, Inyo County, California.

hills. There are, however, many localities where reservoirs can be built among the mountains, a few of which, as in the cases of Bear Valley and Hemet reservoirs, have already been utilized. Other localities possessing many points of advantage still remain; a view of one of these—that at Huston Flat—is given on Pl. XXXVII.

The greater part of the southeastern end of the State consists of broad deserts, broken occasionally by rocky, sterile hills and mountains, these barren lands stretching from the southern end of the Sierra Nevada to the Colorado River. No living streams are to be found beyond the foothills, and only an insignificant amount of water can be obtained from wells. There is not yet sufficient information at hand to determine whether the probabilities of success will justify

large expenditures in exploring for deep-seated waters over any considerable part of this country. Portions of this area are below sea-level, notably Death Valley on the north and the Salton Sink on the south. It is proposed to bring water to the country adjacent to this latter area by a great canal tapping the Colorado River near Yuma and crossing a part of the desert south of the Mexican boundary. This river, shown on Pl. XXXVIII, is one of the largest streams of the country, and at all times of the year discharges a volume sufficient to irrigate hundreds of thousands of acres.

Artesian wells play an important part in the development of considerable areas in California, especially in the southern part of the State, where, from scarcity of water, they are of especial value and importance. Many of the largest wells, however, are in the San Joaquin Valley, upon lands so situated that they could easily be covered by irrigating canals. Water storage, also, has been tried to a large extent, the reservoirs of this State being more extensive and successful than those of any other part of the country.

The estimates of the water supply of this State show that while there is an excess for the humid and subhumid portions, there is a great deficiency for the remainder of the State, there being probably not enough to cover the lands now in private ownership should these be in such position as to have water brought upon them. It is impossible to utilize for agriculture more than a very small percentage of the vacant public lands, especially those in the southeastern part, although it is probable that by means of wells and storage reservoirs small settlements may be established at such localities that the grazing can be used to better advantage than at present.

COLORADO.

In this State there is an excess of water where it is not wanted and can not be used, and a general deficiency where the soil and climatic conditions are best suited for agriculture. The western, mountainous part of the State is intersected by large rivers flowing with great velocity through narrow, rocky valleys, while the eastern part of the State, extending out upon the great plains, has for its broad, fertile lands an amount of water so small that only the areas fringing the principal drainage lines can be irrigated. The total amount of vacant public land in the State aggregates nearly 43,000,000 acres, almost two-thirds of the entire land surface. It lies mainly along the ranges of the Rocky Mountains and to the westward, a few of the lands of the broader valleys, especially in the vicinity of Grand Junction and Montrose, being taken up. In the eastern part of the State the greater part of the fertile areas out upon the plains have passed out of the hands of the General Government, but owing to crop failures and discouragements due to protracted droughts, many of the claimants to the land have moved away, abandoning their homes and such improvements as

they may have made. Thus, although from the number of homestead entries and from the map it would appear that the country must be dotted with houses, the traveler may ride through township after township without seeing a sign of life, excepting a scattered herd. The land, although not vacant according to the designation here used, is so in fact, and can be purchased from its present owners for trifling sums.

Of the land now vacant, it is estimated that 6,000,000 acres are forested or have growing upon them trees (though often sparsely located) of size sufficient to furnish merchantable timber. Much of this has been burned over, so that it is impossible without a thorough examination to reach any definite conclusion as to its value. Besides this, there are probably 7,000,000 acres of woodland, and the balance of the land, in round numbers 30,000,000 acres (p. 494), is without large vegetation, although furnishing fair grazing during at least parts of the year. Much of this land, especially that beyond the main range of the Rockies, consists of high plateaus deeply cut by gorges, and is accessible only by rocky trails.

The streams of the State of chief value in the development of the lands are the Platte, Arkansas (Pl. XXXIX), Rio Grande, and their tributaries. Along all of these agriculture has progressed rapidly, and has reached a high state of development, rivaling California in success in the cultivation of all but the semitropic fruits. The ordinary flow of the streams is utilized to its fullest capacity, and, especially on the South Platte drainage, large numbers of reservoirs have been built in or near the foothills for the purpose of holding flood waters. This method of increasing the available supply can be utilized to a greater extent, as there are still many localities where water might be held at moderate expense. The examinations carried on by this Survey have shown the existence of good reservoir sites, especially in the basin of the Arkansas, the most notable of these being that at Twin Lakes. By holding the greater part of the flood waters, it will be possible to extend the area under cultivation, but the amount of land which has already passed into private ownership is so great that there is little probability of sufficient supply being obtained for any considerable part of the public lands of the eastern half of the State.

The vast Rocky Mountain region, occupying the central part of Colorado, consists largely of vacant land whose chief value lies in its undeveloped mineral wealth, and next to this, in its forests and capability of producing trees. The altitude is too great, even in the valleys, and the climate too severe, to produce anything but forage plants. To the west, beyond the mountains, are the plateau lands previously mentioned, high and arid, and far above the reach of the water which flows in turbulent streams through the narrow valleys. The chief value of these lands is in the grazing, although there are tracts of considerable extent which should be devoted to forest production. A number of reservations for this purpose have been made in Colorado, the principal

ARKANSAS RIVER, BELOW MOUTH OF CANYON, COLORADO.

one being the White River Plateau Timber Land Reserve, in the northwestern part of the State. This embraces over 1,000,000 acres. Second to this in size is the Battlement Mesa Forest Reserve, embracing over 800,000 acres. There are other similar tracts of less extent, but the entire area thus covered is less than one-third of the probable extent of the mountain forests (pp. 482, 492).

The water supply from wells is an important feature, especially out upon the great plains, where there are no surface streams, but where it is possible to obtain an amount sufficient for the irrigation of small patches of land, besides drinking water for cattle. In the vicinity of Denver, Pueblo, La Junta, Lamar, and in the San Luis Valley are areas where artesian conditions are known to exist, and where flowing wells are used for domestic purposes, and to a small extent in agriculture.

IDAHO.

Idaho is considered one of the best wooded States of the arid region, its narrow northern end being covered to a large extent with forests and woodlands. The broad southern part, however, extends over the lava plains bordering Snake River and is destitute of the larger vegetation, the most conspicuous plant being the so-called sagebrush, which grows on this rich soil often to extraordinary size. The water supply of the State is large, but, unfortunately, only a part can be utilized to advantage, as the most important river—the Snake—soon after leaving the mountains cuts for itself a deep canyon in the lava, and by cascades and rapids falls to a depth of hundreds or thousands of feet below the plains.

The vacant land of the State—over 75,000 square miles—forms nearly nine-tenths of the total area (p. 478). The great mass of it, untouched by settlement, lies in the almost unexplored mountain masses of the central and northeastern parts of the State. On the great lava plains of the Snake, also, are many miles of vacant land, the soil, though fertile, being too dry to attract the pioneer. Along the northwestern edge, adjacent to eastern Washington, the cultivation of cereals by dry farming is successful; and in the valleys of the Weiser, Payette, and Boise many irrigating systems have been constructed, carrying water to farms on the benches and lowlands. There is still a surplus of supply, and the area thus cultivated can be extended, although it is probable that the lands now in private ownership will demand all of the water easily obtainable.

Considerable areas of vacant public land can probably be watered by large canals heading on the Snake River near or below Idaho Falls, and small tracts can doubtless be made valuable by the construction of storage reservoirs upon or near the edge of the lava plains. Several such reservoirs, as, for example, in the vicinity of Mountain Home, have been built and are in successful operation, the relatively low altitude and genial climate rendering possible the production of prunes and similar fruits.

There are a number of deep wells in Idaho, the most notable being in the vicinity of Boise. Some of these furnish hot water, and are of especial value as supplying heat for various purposes. Attempts to penetrate the lava plain have not been successful, although, judging from the occurrence of water in large springs at various localities, it is probable that a supply may be obtained at some points in this manner. The volume of several of the springs emptying into the Snake River is extraordinary, and it is possible that in the future the water power from these springs, or from the river itself, may be utilized to pump water upon the high, fertile lands.

INDIAN TERRITORY.

This area, estimated to include 31,000 square miles, is wholly devoted to the use of the various Indian tribes. It is as a whole humid and well supplied with streams and springs. The greater part is tree covered, it being estimated that over 8,000,000 acres are covered by forests containing more or less timber of value, and 5,000,000 acres wooded. About one-third of the whole area is open or treeless, the greatest extent of grazing land being in the Creek and Cherokee countries, on the rolling lands between the streams tributary to the Arkansas River. Within the wooded areas are stretches of open country, making it difficult to obtain an accurate idea of the relative amount of forest and prairie. If the lands of the Territory are allotted in severalty, there will be left a considerable area of humid or subhumid country to be restored to public entry.

KANSAS.

Although, as previously stated, Kansas contains a very small amount of land belonging to the National Government, yet there are, especially in the western counties, thousands upon thousands of acres to all intents and purposes vacant, title having been acquired by settlers at various times within the last decade. Much of this land probably belongs to loan and trust companies, while considerable tracts have been abandoned and offered for sale in payment of taxes. During the years 1886 and 1887 settlers flocked to western Kansas and eagerly took up land wherever a piece of sufficient size could be had. Town sites were laid out in every direction, and buildings sprang up as by magic. Every point of vantage to secure the permanence of these towns was seized upon, no matter how trivial. Especially was this the case with the towns contesting for county buildings and offices. Nearly every town suitably located put in its bid, and the rivalry became so intense that a petty warfare was inaugurated.

Railroads and local improvements were rapidly constructed or entered upon, and bonds were freely voted for every imaginable kind of enterprise, the counties assuming liabilities for public buildings and for the inducement of railroad construction far in excess of their resources. At the

same time money was loaned freely to the settlers wherever any apparent security could be offered, and agents of Eastern loan companies, rendered reckless or dishonest by the prospect of commissions, bid against one another for opportunities to place loans upon real estate. The stories related of the extravagance of these years, or, rather, short seasons of growth, are almost beyond belief. Men are reputed to have taken up land and secured title simply for the purpose of obtaining loans. Others, with honest intentions of securing homes, were led by the ease of borrowing to expend sums for useless implements and unessential conveniences. Nearly every homestead was mortgaged, often for sums many times its present value, the mortgagees being usually clients of some Eastern trust company, and in innumerable cases persons in moderate circumstances who took this method of investing their earnings for the sake of obtaining a rate of interest in excess of that prevailing in older, settled communities. Although the climate was known to be subhumid and the land subject to droughts, yet persons interested in land sales and in urging onward the excitement did all in their power to diffuse the belief that under the influence of settlement the weather conditions were becoming more favorable and that with the breaking of the prairie sod, the building of railroads, and the planting of trees the rainfall during the growing season would be increased, rendering this part of the State as suitable for agriculture as the eastern end.

The extravagance, misrepresentation, and fallacies which led to the rapid disposal of the lands of western Kansas received a check by the continued droughts which followed year after year and the resulting loss of crops and poverty of the people. A large proportion of the settlers were compelled to leave through actual want; others, becoming discouraged, or perhaps attracted by some new locality, packed up their household effects and got away as best they could, abandoning their farms and homes. These lands now lie idle, the fences are down, and the houses, windowless and doorless, dot the plains in every direction. In some instances, a farmer more fortunate than his neighbors in adapting his methods to the climatic conditions, or perhaps successful in cattle raising, has gathered together a number of these deserted houses, hauling them from all directions, and perhaps adding them to his own as an enlargement, or scattering them about in a motley fashion in his own dooryard, for use as barns and sheds.

It was early recognized that the permanent occupation and development of much of this country rested upon the possibilities of obtaining water. Along the Arkansas Valley a number of canals were constructed, those in the vicinity of Garden City being among the earliest on this stream, having priorities, it is claimed, even over many of the older ditches in Colorado. At the time these canals were built the Arkansas was supposed to be a perennial stream, and little, if any, doubt was entertained as to the ability to obtain water at all times and seasons. But with the development of irrigation in Colorado, and the

rapid increase of the number of canals and of the area of land cultivated, there has been a diminution of water entering Kansas, except during time of flood, and through a great part of the growing season the river is completely dry, or at most contains stagnant pools. Many canals constructed at great expense have been abandoned, or maintained in such shiftless, inefficient manner that the farmers under them are disheartened from further attempts at cultivation by means of the water. It is possible that with proper management, and the diversion of water during flood, much of the land under the canals might be well watered once or twice a year, and produce better crops. With improved methods of irrigation, and with the incentive of the examples of successful farmers, some of these old canals will undoubtedly be utilized in the future.

The valley lands of the Arkansas, however, are not dependent upon the flowing waters, but possess a great advantage in that they can be irrigated from another source. This source is the enormous volume of water stored in underlying pervious soils, easily accessible by wells or deep trenches. The existence of the subsurface waters of the river valleys of western Kansas has long been known, and has often been brought to public attention by popular articles and by official reports. Like every other natural resource, its importance, at one time little recognized, has been seized upon by the so-called "boomers" and exaggerated to the extent of creating distrust and depreciation. It is, however, one of the most important of the natural advantages of the State, and one upon which the foundations of prosperity must be carefully laid.

By a thorough employment of the underground waters, with the best methods, much of the vacant land of the State will be utilized for agriculture, and the remainder can become a source of revenue, indirectly, at least. Taking the Arkansas Valley, as best illustrating these conditions, the general statement may be made that water can be had everywhere within the valley at moderate depths, and in quantities such as to be inexhaustible to ordinary pumping machinery if properly installed. The volume and the rate of delivery are of course dependent largely upon the coarseness of the sands or gravels and upon the thickness and extent of the beds. Careful surveys have not as yet been made to determine the extent and character of these beds, but sufficient work has been done to obtain a broad comprehension of the subject.

In the portions of western and central Kansas where wells can not be obtained at moderate depth it will probably be practicable to store considerable volumes of water by closing the outlets of natural depressions. Favorable localities, although somewhat rare can be found in nearly every county, and by the proper construction of substantial earth dams considerable volumes of water can be held for use upon the lower lands. In one instance, at least, water thus stored has been pumped for use

upon an orchard, and the success attained in this way should induce others to try similar devices. A more detailed discussion of the water supply of the western part of the State is given in the following paper by Prof. Robert Hay, this being the result of a reconnaissance carried on during the fall of 1894.

MONTANA.

Though second to California in size, Montana contains by far the greatest extent of vacant land, there being of this 114,057 square miles, equivalent to 78.49 per cent of the total land surface. As shown by map (Pl. XXXV), the lands in private ownership are irregularly scattered, the greater part being, however, along the eastern slope of the Rocky Mountains, from about the vicinity of Great Falls southward to the Gallatin Valley. Out upon the great plains a very small amount of land has been taken up. The State is crossed by the broad belt of lands granted to the Northern Pacific Railroad Company, but the railroad selections as yet aggregate only a little over 5,000,000 acres. The forest and wooded areas are in the western end of the State, embracing the mountainous region from the foothills of the Rocky Mountains westward to the Bitter Root Range. It is estimated that about 17,000,000 acres can be designated as forest, although a considerable portion of this has been burned over, and that a slightly larger amount has scattered woodland, some of this including the irregular mountains to the east of the main range. As yet no reservations of forest lands have been made within the State, although there has been some discussion as to the practicability of setting aside some of the lands in the vicinity of Flathead Lake.

The water supply of the State within the mountain region of the western portion is large, and the eastern part is traversed by two great streams—the Missouri and its tributary, the Yellowstone. Both of these carry large volumes of water, the summer discharge of each being probably not less than 5,000 cubic feet per second. They are bordered for the greater part of their distance by bluffs, and although there are considerable tracts of lowlands lying in long strips, first on one side and then on the other, yet the great body of rich, undulating plain is at an elevation of several hundred feet above the water level. Each of these rivers has a considerable fall, and it is possible by means of long canals starting well upstream to wind about along the faces of the bluffs and finally bring the waters out upon the broad lands. Reconnaissance has shown that although the engineering features are not insurmountable, the expense of such irrigation will probably be so great and the prospect of immediate returns so small that the attempt should not be seriously considered at the present time.

On account of the difficulty of diverting water from the larger streams, development has taken place among and near the foothills, where the smaller creeks can be utilized by comparatively inexpensive

works. Nearly all of the headwater streams of the Missouri are thus used, and in the Gallatin Valley, especially, the low-water flow of the streams appears to be entirely appropriated. The main Gallatin, Madison, and Jefferson, however, still discharge considerable volumes into the head of the Missouri, as shown by the measurements conducted in the vicinity of Three Forks and on the main river at Townsend. There are many thousands of acres of unutilized land, some of it still belonging to the National Government, in the valleys in the region and to the north of Helena, to some of which it may be possible to take a portion of this surplus water of the tributaries of the Missouri. In the mountains west of Great Falls are still a considerable number of streams whose waters are not fully appropriated, and whose floods can be saved for use upon the broad extent of Government land.

Beyond the mountains, in the western part of the State, the streams are large and have rapid fall. The valleys through which they flow, however, are usually narrow, and there is far more water than is needed for the arable lands. Toward the northwestern corner of the State the climate becomes more humid, and to the north of Flathead Lake the bottom lands are occasionally cultivated without irrigation.

The total available water supply of the State is estimated to be sufficient for about 11,000,000 acres of land, or a little more than has already been disposed of by the General Government. It is probable that in the aggregate no very considerable acreage of the land now vacant can be brought under irrigation without taking the waters which could be used on private lands, unless large projects, such as those involving the use of the waters of the Missouri and of the Yellowstone, are undertaken.

NEBRASKA.

In many respects Nebraska is similar to its sister State, Kansas, but since it extends farther to the westward, and on the north includes considerable areas of sand hills, the amount of vacant public lands is far greater. In the aggregate this amounts to 17,186 square miles (p. 478), or 22.36 per cent of the State—a little less than one-fourth of its whole area. There has not been so much excitement and misrepresentation regarding the western portions of Nebraska as of Kansas, and therefore the disappointments, losses, and suffering have not been so noticeable. Thousands of families, however, have failed in their hopes of making desirable homes, and following seasons of drought many persons have sought assistance from public charity. It is now generally recognized that throughout a great portion of the western end of the State agriculture can be successfully carried on only by means of water artificially applied, and also that even away from the rivers it is possible to obtain sufficient water to cultivate small areas.

The principal body of the vacant lands lies in the region to the north of North Platte River and among the foothills in which the various

tributaries of the Loup take their rise. It also includes tracts of similar sandy nature to the south of the river. In this region the rains soak into the ground without forming streams, leaving the surface so dry that only a very scanty vegetation survives. Occasionally there are years in which the rainfall is so well distributed that the grasses reach a considerable height, furnishing excellent grazing; but again for a succession of seasons droughts burn the vegetation, and the winds blow the sand, changing the shapes of the hills. In these hills are occasionally pools of water, resulting probably from the seepage from adjacent hillocks, the escape of the water downward being evidently prevented by impervious layers. Even in this light soil, in the valleys between the hills, it has been found possible to raise early crops of vegetables, especially if a small amount of water can be obtained. Thus homes have been made there, the farmers raising a sufficient amount to supply their own needs, and depending upon cattle or sheep raising for profitable occupation.

The principal source of water supply of western Nebraska is from the North Platte River, which in this State occupies a broad, sandy bed, the stream in summer being reduced to a depth of only a few inches and spreading out in innumerable channels, aggregating a width of a half mile, or even more. At times of extreme low water the discharge shrinks to less than 1,000 feet, but this amount could probably be augmented by suitable devices for bringing out the water stored under the bed and flood plains. The valley lands along the river are relatively narrow, being in places intercepted by high bluffs. Most of these flood plains have been already covered by irrigating ditches, and on all of them water can be procured at moderate depths by wells. Back from the river the depth to the water increases, but from various attempts made it appears probable that an amount sufficient for domestic use, and even for agriculture on a small scale, can be procured at most points.

In Nebraska, as in Kansas, considerable popular interest has been manifested in the development of a water supply by means of wells pumped by windmills or by engines run by steam or gasoline. Successful experiments have been made in many counties, and it seems more than probable that throughout the greater part of the State prosperity will follow experience and the resulting improvements in methods. In some cases, however, water has not been found at moderate depths, or has been so brackish as to be unfit for use. It is necessary to have a thorough examination made of the geological structure of the country before it is safe to predict the extent to which wells can be utilized.

The available water supply from the streams of the western part of the State has been estimated to be sufficient for 1,500,000 acres, this estimate not including the rivers of the more humid portions, where water is not used for agricultural purposes.

NEVADA.

This State contains the largest proportion of vacant public land, over 95 per cent being still in the hands of the National Government. It is known as the most arid of the States, its water supply when compared with the vast area of the surface being relatively insignificant. There are, however, a considerable number of large streams, and on the side of each notable mountain mass are springs and small creeks sufficient to irrigate farms along the edges of the valley. The most prominent river is the Humboldt, whose drainage is almost entirely included within the northern part of the State. Its waters, however, are not so thoroughly utilized or so important as those of the streams which, rising in California, flow across the State line. The principal of these are the Truckee, Carson, and Walker. In the case of each of these rivers the disadvantage of drawing State lines irrespective of natural divisions is apparent. The upper catchment areas, containing reservoir sites where floods might be held for use in dry seasons, are situated in the State of California, and in counties whose inhabitants have no interest in the development of the lower lands. The most fertile areas, and those upon which the water could be used to best advantage, are in Nevada, but under present conditions it is impossible for the owners of these lands to utilize many of the best storage sites, not only on account of the expense, but also on account of the difficulties of securing favorable legislation from another State.

The small portion of Nevada which has been disposed of by the General Government is mainly in the extreme western part, in the valleys near the California line. Scattered patches of land disposed of in one way or another are also to be found along the Humboldt River and in some of the interior valleys, but in the vast expanse from the Utah line southwestward across the State to the California line there is scarcely a spot taken up. On the map the scattered dots exaggerate the actual extent of land in private ownership, since it is impossible to represent these in their true proportion on this scale. Of this land comparatively little has been obtained directly from the National Government by the settlers, the greater part being portions of the 2,000,000-acre grant made by Congress to Nevada for school purposes in place of sections 16 and 36, usually reserved for this purpose in each township.

NEW MEXICO.

The Territory is characterized by the enormous Spanish grants made previous to the acquisition of the country by the United States and subsequently confirmed by patents from the General Land Office. Some of the best portions of the country have thus passed into private ownership. There still remain vacant, however, 85,302 square miles, or 54,593,280 acres, this amount being very nearly seven-tenths of the entire Territory. The greater part of the vacant land is in the south-

ern and southeastern portion, adjacent to Texas, and also in the northwestern portion, near the Navajo Indian Reservation. Through the center of the country the Rio Grande flows, furnishing an ample supply of water for the lowlands. This is the principal river, and is notable not only from this fact but from the interstate and international questions which are becoming more and more pressing each year. The stream rises in southern Colorada and flows across the San Luis Valley, in which some of the larger canals of the United States derive their supply from various points along its course. Crossing the Colorado State line, the river enters narrow canyons and passes in succession through gorges and valleys until it reaches the narrow pass above El Paso. Here it becomes the boundary between the Republics of the United States and Mexico, and as such has international importance.

The loss of water by evaporation in passing through the broader valleys, combined with the large diversions of waters from its sources in Colorado through New Mexico, tends to diminish the flow of this stream, so that long before it has reached the southern boundary of New Mexico its bed is often dry in summer. As a result the canals on either side of the river, rendering habitable the country about El Paso and the Mexican towns, do not obtain a sufficient supply; and with the continued diversions above, the prospect for the future of these towns is not bright unless water can be obtained in some other way or held by storage dams. Measurements are now being made of the volume of the river at various points, in order to give data for the better discussion of the problems involved.

In the southeastern part of the Territory is the Pecos River, flowing southward into Texas and finally uniting with the Rio Grande. This stream, especially in the lower part of its course, has a large perennial supply, due in part to the springs which occur in the vicinity of Roswell and farther south. The irrigating system[1] along this river is one of the most notable in the United States, on account both of its magnitude and of the thoroughness with which it has been planned and executed. One great advantage has been possessed by the company owning this great system, in that at the time work was begun there were few if any small irrigating ditches whose water rights interfered with the laying out of canals and reservoirs. These, therefore, could be designed, to utilize the natural resources to their fullest extent. One of the most notable features is the enormous size of the storage reservoirs, constructed at relatively small expense. The topography has been unusually favorable, and has made possible the ponding back of the Pecos River for many miles by dams of heights not greatly exceeding 50 feet. The dam of one of these storage reservoirs, that at the head of the main canal, has been described and figured by Mr. Wilson.[1] During

[1] Thirteenth Annual Report of the United States Geological Survey, 1891–92, Part III, Irrigation; American Irrigation Engineering, by Herbert M. Wilson, C. E., pages 187–191.

1895 a still larger reservoir, known as Lake McMillan, has been built about 10 miles above the dam mentioned, having an estimated capacity of 138,000 acre-feet. The dam holding back this immense amount of water is 1,686 feet long and only 56 feet high at the lowest point in the stream channel. The water supply for these storage reservoirs is obtained from the flood discharge of the stream and partly from the spring rivers above mentioned. The remarkable springs from which these streams flow are comparable to those of Texas, and may be considered one of the greatest sources of permanent wealth for New Mexico. In the vicinity of these springs are a number of comparatively shallow artesian wells, few if any being at a depth of over 300 feet. Some of this water is used for irrigation in a small way.

With the exception of the Rio Grande and Pecos, the streams of the Territory are small, and many of them are intermittent in character, flowing only in times of flood. The principal exception is the San Juan River, in the extreme northwestern corner of the Territory. This river receives a large perennial supply from the mountains of Colorado.

The aggregate water supply of New Mexico available under ordinary circumstances has been estimated to be sufficient for about 4,000,000 acres, or about one-fifth of the land now in private possession. It is probable that by the development of wells and by storage systems considerable areas of the public land may be reclaimed. The greater part, however, will probably have its best use for grazing purposes and for the production of firewood and timber.

NORTH DAKOTA.

In this State over four-tenths of the land area has been disposed of and about one-tenth reserved, mainly for the use of the Indians. The remainder, aggregating in all 33,090 square miles, or 47.14 per cent (p. 498), still belongs to the General Government and is open to settlement. This vacant land is found in small patches in the central portion of the State, and increases in extent toward the west, the third of the State adjoining Montana being almost entirely unoccupied. In this part of the State, especially beyond the Missouri River, the surface is undulating or deeply ravined and so greatly cut by drainage channels that agriculture, except in a few valleys along the principal creeks, can not be conducted on a large scale. In the eastern end of the State, in the James and especially in the Red River Valley, are the great wheat farms which have rendered this country famous. The greater part of the public land is mainly valuable for grazing, although there are local occurrences of beds of impure coal, or lignite. Very little of the land is wooded, except, possibly, along the streams.

There are few sources of water supply available for the irrigation of the arid public lands of this State. The Missouri flows through the State and carries a large volume of water, but it is bordered by bluffs, and the fall of the river is so slight that it has been found impracticable

to attempt to divert any of the water by means of canals. Its tributaries, flowing in from the west, are mainly intermittent, and they, too, are at a level so much below that of the arable lands that, except in a few instances, it will be impossible to use them for irrigation. The principal dependence must be placed upon wells, and fortunately these can be had over large areas. The deep wells in the James River Valley are artesian in character, delivering large quantities of water. In the Red River Valley, and also at localities to the east of and adjacent to the James River Valley, are shallower artesian wells, obtaining their waters from the glacial gravels. The water of nearly all of these flowing wells is impregnated to a greater or less extent with mineral salts, rendering them somewhat unpalatable and necessitating considerable care and skill in applying the water successfully to the crops. By proper cultivation and judicious use of the water, it has been proved that irrigation can be conducted through a series of years without overloading the soil with injurious mineral matter. The extent of the artesian basins has not yet been clearly defined, nor have the conditions of the western part of the State been studied with a sufficient degree of care to give a thorough knowledge of the probabilities of obtaining water supply at various points by wells, but from what is known it is probable that small farms can be located in nearly all of the western counties, the surrounding lands being used for cattle ranges.

OKLAHOMA.

The lands comprising this Territory were held for the benefit of the Indian tribes until settlement had progressed westward beyond them and the adjacent areas in Kansas had been almost completely taken up. These lands, lying partly within the humid region, were long looked upon with covetous eyes by the white man, and many illegal attempts at settlement were made. Arrangements were finally entered into with various Indian tribes for purchasing these lands, and after survey they have been thrown open to the public. During the time necessary to complete the purchase and subdivision, popular attention was drawn to these lands, and when they were finally thrown open to entry there was a great struggle to secure possession of the more desirable spots. The last of these great scrambles for public lands was that following the opening of the Cherokee Outlet by proclamation of the President on September 16, 1893. This outlet contained nearly 6,500,000 acres, and was divided into seven counties. The great influx of population on that and succeeding days can best be judged by the fact that within the week following September 11 about 115,000 certificates were issued, entitling the holders to enter upon the lands after the date named for the purpose of taking up homesteads or town lots Within a few days over thirty towns were established, some of which reached a population of more than 5,000. Over 20,000 homestead entries were made within the next six months. Of the entire area of the Outlet, there was suffi-

cient to make fewer than 40,000 homestead claims of 160 acres each. When it is remembered that the greater part of the western half of the area is unsuitable for homesteads on account of aridity, it is apparent that there were from five to six times as many certificates issued as there were suitable homesteads. As a result the struggles over the most desirable localities were severe and prolonged. Almost innumerable contests have arisen, both privately and in the courts. Owing to the still unsettled condition of affairs in the Cherokee Outlet and in other parts of Oklahoma, it is impossible to make satisfactory estimates as to the amount of public land still vacant. It is probable, however, that for the Territory as a whole there is less than 40 per cent now open to entry, this being principally on the western side and in the long strip north of the Panhandle of Texas, now known as Beaver County. The lands here are similar to those of southern Kansas, are in general fertile, slightly undulating, and occasionally produce good crops. The dependence for water supply must be placed mainly upon wells, as the streams of this part of the country are small, and unless reinforced by storage reservoirs are of little use.

OREGON.

In this State the great bulk of the land to the east of the Cascade Range still belongs to the National Government, together with a considerable area of forest along the coast and among the high mountains. The aggregate area of vacant public lands is estimated to be 55,887 square miles (p. 478), or 35,767,680 acres, this being a trifle less than three-fifths of the area of the State. The principal tracts disposed of to individuals lie in the valley of the Willamette and in the smaller valleys to the south and west. In the extreme eastern portion are also numerous entries, in the valleys among the Blue Mountains, where water can be obtained. Next to Washington this State is one of the best timbered in the West, the estimated area in forest being over 20,000,000 acres, and in woodland 17,000,000 acres (p. 482). Part of this has, however, been burned or cut over, and the present knowledge of the condition of the timber is somewhat meager, so that these figures may be above the actual facts. The largest forest reserve in the United States, that of the Cascade Range, lies within this State. It includes nearly 4,500,000 acres, and extends from the Columbia River on the north, south along the mountains nearly to the California line. Besides this there are smaller reservations of relatively insignificant size.

The greater part of the vacant public land is within the great interior basin, the streams of which do not have sufficient volume to cut their way to the ocean. They flow for a short distance from their sources among the mountains, and gradually dry up, or flow into some lake or marsh from which the water is evaporated. The supply is very small in comparison with the land to be supplied, and it will be necessary to use storage reservoirs and well water, wherever it can be obtained, in order to utilize the land.

SOUTH DAKOTA.

In South Dakota the area vacant aggregates 25,204 square miles, or nearly one-third of the area of the State. In addition to this should be considered the large area reserved—15,951 square miles—the greater part being for the use of the Indians. These Indian reservations will probably be cut down from time to time, thus adding to the area in the hands of the Government. Nearly the whole of this vacant land is west of the Missouri, between it and the Black Hills. Much of it is "bad land," and has no apparent value, except possibly for grazing. Along the streams, however, are many places where farms can be made, and settlement is progressing steadily into this area. In and about the Black Hills nearly all of the well-watered lands have been taken up, but considerable tracts of forest are still in the hands of the Government. These forests, however, are being cut or burned over, so that the remaining timber will probably have little commercial value in the future.

In the eastern part of the State, where the lands are now almost completely in the hands of private owners, the rainfall is usually well distributed throughout the summer and crops are fairly successful; but droughts are of frequent occurrence, and in many of the counties there has been considerable suffering owing to the fact that all dependence has been placed upon some one crop, the conditions for which were unfavorable. Irrigation has been introduced in a small way, and the people are being educated to see the benefits of cultivating small areas by means of an artificial supply of water. The James River, however, the principal stream east of the Missouri, carries but a small amount of water and has such slight fall that it has not been found practicable to build irrigating ditches from it. In a few places water is lifted from the river by pumps, some of these being driven by the stream itself.

The most important sources of the water supply of the James River Valley are the artesian wells, which bring up water in considerable quantities from various depths. This water rises above the surface, and at some places has sufficient pressure to drive machinery, besides furnishing municipal supply. By connecting suitable fire hose to the pipes, a stream of water can be thrown over the highest buildings of many of the more important towns. The value of this artesian supply is very great, not only for municipal and domestic purposes, but also for agriculture. Unfortunately, however, much of the water is impregnated with mineral matter, rendering it essential to use considerable care in applying it to growing plants.

West of the Missouri River the water supply is relatively small and precarious. Attempts to secure artesian water have not as yet been made within the great body of the public lands near the Black Hills, streams and springs combined furnishing ample water for the lands in that vicinity. It is probable that in many places wells can be success-

fully drilled, and in others storage reservoirs can be constructed to hold flood waters, rendering successful agriculture possible within the greater part of the lands now unutilized.

TEXAS.

As previously stated, this State, on coming into the Union, retained possession of the lands within its borders and instituted its own methods as to the disposal of the unclaimed areas. The greater portion of these have now been disposed of, but the State still retains title to many millions of acres, situated mainly in the extreme northern and western extremities. In northern or Panhandle Texas the lands are high, being upon the Llano Estacado, where water is obtained with difficulty. Deep wells, however, have been successful in obtaining sufficient for stock purposes. In the western end of the State, beyond the Pecos, the country is more sterile, is often desert-like in character, and over large tracts does not at any time of the year support vegetation sufficient even for grazing.

The greater part of Texas is well watered, the most notable feature of the supply being the occurrence of large perennial springs in an irregular line across the central part of the State, notably at Austin, San Marcos, San Antonio, and Del Rio. There are also a number of horizons at which artesian water is found, and deep wells, especially valuable for city supply, have been put down at various points from Waco to Galveston. A more complete discussion of the waters of the State will be given in forthcoming reports by Prof. Robert T. Hill, and in other publications now in preparation.

UTAH.

Utah includes an area of 84,970 square miles of the region lying almost in the center of the western or arid half of the United States. By reason of its medial position and widely varied topography, as well as of its progress in agriculture by irrigation, it typifies more nearly than any other one political division the conditions prevailing in the arid regions. A description of its water resources and the method of their employment—the deficiencies of supply, and the improbability or impossibility of ever utilizing large tracts of desert land—epitomizes the narrative of conditions throughout the West. Of the area above mentioned 2,780 square miles, or 3.27 per cent, is water surface. Deducting this amount, the land area is 82,190 square miles, or 52,601,600 acres.

A large proportion of the surface consists of high mountains, whose altitudes range from 10,000 to 12,000 feet. The greater part of the Territory is at an elevation of from 4,000 to 6,000 feet above sea-level, 46,000 square miles, or 54 per cent, of the land surface being at this height. A small amount, 1,500 square miles, is lower, being mainly in the extreme southwestern part of the Territory, along the Colorado River and its tributaries. The remainder of the area, 37,470 square

miles, or 44 per cent of the total, is above 6,000 feet and consists of elevated plateaus or mountain areas containing relatively few valleys suitable for occupation.

Two great catchment basins or systems of drainage receive the flowing waters of Utah. These are the Colorado River system and the great interior basin, of which the area tributary to Great Salt Lake, Sevier Lake, and other sinks forms a part. In area within the Territory these are of almost equal extent, the Colorado basin comprising 41,422 square miles, and the interior basin, with its numerous lost streams, including 43,548 square miles.

The vacant public lands in Utah aggregate 43,077,120 acres, or 67,308 square miles, being 81.89 per cent of the land surface of the entire Territory. Of the remaining area 7,812 square miles have been disposed of in various ways to individuals or to railroad and other corporations, and about an equal area, 7,070 square miles, or 8.60 per cent of the entire land surface, is held for Indian and other reservations. These reservations contain much good agricultural land to which water can be taken, and it is probable that many of these will from time to time be thrown open to entry and settlement under the homestead laws. Adding the area of these reservations, therefore, to the vacant public lands, it appears that over nine-tenths of the area of this Territory is still at the disposal of Congress.

That portion of Utah (7,812 square miles, or 9.51 per cent) which has passed out of the ownership of the General Government is widely scattered, but the main body is in the northern-central part of the Territory, and extends in a comparatively narrow strip west of the Wasatch Mountains, embracing the valley lands to the east of Great Salt Lake, and thence running southward along the east side of Utah Lake and through the valleys of central Utah. The lands in private ownership, when depicted upon the map of the Territory, outline the valleys through which flow perennial streams. Besides the larger groups of settlements above described, which are mainly within the great interior drainage basin, there are scattered areas of settlement trending southwesterly across the Territory down to its lower corner on the Virgin River. These are principally on the headwater valleys of streams tributary to Colorado River, far above the great canyons which traverse the southeastern and southern portions of the Territory.

The Land Office surveys and subdivisions are in a general way confined to this central portion of the Territory. In the aggregate, about 24,000 square miles have been thus subdivided, this being a little less than 30 per cent of the entire land surface. Comparing the area surveyed with that which has been disposed of, it is apparent that this work has progressed over an extent of territory about three and one-half times that which has been finally disposed of. The rate of disposal of the land is comparatively uniform, averaging for the last five years nearly 208,000 acres, or 325 square miles, per year, or 0.39 per

cent of the entire area of the Territory, and 0.48 per cent of the total vacant land. If this rate were kept up continuously, it appears that it would require over two hundred years to exhaust all of the lands open to settlement. From the necessity of the case, however, this rate is constantly decreasing, as the better lands, or those more favorable for immediate development, are first taken, restricting the choice year by year. The rate of disposal will be lessened also by the fact that the railroad lands included in the above will before many years be completely selected, and will not appear in this total.

Of the land disposed of, which in round numbers amounts to 5,000,000 acres, 747,124 acres, or about one-seventh, consists of land selected by the Union Pacific and Central Pacific railroads, under the act of July 1, 1862, and subsequent enactments. The remainder, 4,262,876 acres, has been taken up mainly under the operations of the homestead, desert, and preemption laws, a relatively small amount being acquired by sale of coal and other minerals, or entered by means of warrants and land scrip. In other words, it appears from these figures that 8.10 per cent of the area of Utah is now held by individuals, or perhaps to a small extent by companies, through titles obtained by purchase or settlement under general land laws, and that an amount not exceeding 1.42 per cent is held by purchase from railroad companies. All of these are selected areas, and presumably contain the best farming lands of the Territory, or at least those considered best under present conditions, and which could most easily be brought under cultivation by irrigation. There are unquestionably other areas possessing soil as fertile, but these have not been taken up because of the difficulty or impossibility of obtaining water.

Besides the 747,124 acres of land selected by the railroad companies, these corporations virtually own an enormous tract of land which has been included in the estimate of vacant or reserved public lands, not having been selected and patented by the companies. This tract extends in a belt across northern Utah, and consists of the odd-numbered sections for 20 miles on each side of the constructed line. Assuming that the length of the railroad line across Utah is 200 miles, this would entitle the railroads to about 2,560,000 acres, or nearly 5 per cent of the land area of the Territory. Under present regulations these lands are usually not selected and patented until sold by the railroad companies, and thus taxation is avoided.

For comparison with the figures given above may be quoted the result of the enumeration of the farms of Utah prepared by the Eleventh Census. These results, obtained by visiting every farm in the Territory, show that, in round numbers, there were, in 1890, 1,323,705 acres included within farms, according to the general acceptance of that term. That is to say, the farm area of 1890 formed 26.47 per cent of the lands now disposed of by the General Government, and 2.52 per cent of the total land area of Utah; or the farm area could be extended four times before including all of the selected lands of the Territory.

But not all of the area included in farms is improved or under cultivation The census report on irrigation (p. 218) shows that 263,473 acres were irrigated, or about one-half of 1 per cent of the entire area of the Territory, or nearly 20 per cent of the farm area. Assuming that water could be taken to all of the lands above mentioned, the irrigated area must be increased five times to equal the extent of the farm area, or about sixteen times to equal the area of the land now mainly in the hands of individuals who have purchased or homesteaded it, presumably for agricultural purposes.

Not only is the amount of land now in the hands of individuals enormously greater than the area irrigated or improved, but each year large additions are being made, as shown by the rate of disposal noted above. Annually titles are being acquired to an additional area of land nearly as large as the total area irrigated in the census year.

The matter of most direct public interest in regard to the vacant public lands of Utah is that of their reclaimability and value in building up the future State. As shown by the above figures, these lands form nearly 90 per cent of the total area, but they are of such character that settlers have passed them by in choosing localities for their homes. A great part of them consists of mountain ranges or elevated plateaus, gashed by gorges and canyons in such a way that they are almost inaccessible, and as a rule they are in a climate so arid that nothing can be raised without the application of water. Disregarding areas the soil of which is too rocky for cultivation, there still remain enormous areas, of unknown extent, the reclaimability of which depends wholly upon the question of water supply. It has already been shown that the area under irrigation in the census year was but about one-half of 1 per cent of the total area of the Territory. Further than this, it may be said that statements from thousands of irrigators in the Territory demonstrate that the available water supply was largely taken up, and that even this area was not so fully watered that year, on account of scarcity of water, as it should have been in order to produce the best results. In other words, the accessible water supply has been used for this comparatively insignificant area. But there remain the flood waters, and those of the nonirrigating season, and the waters of large rivers which, from engineering difficulties, have not been employed.

The use of stored waters for the reclamation of arid lands is still somewhat a matter of conjecture as to financial results. The only known successful projects on a large scale are those of parts of California where the value of the products is exceptionally large, so that it is impossible to predict with any degree of certainty the proportion of flood waters which can be utilized profitably. The future reclamation of these vacant public lands depends not so much upon the quantity of water as upon the feasibility of any given project from a financial standpoint, for it is hardly to be assumed that even the Government, State

or national, will invest money in works which will not pay their operating expenses and a very small amount toward a sinking fund.

The investigations of water supply, which have been carried on for a number of years, have been confined to a relatively few streams, but the general conclusion reached is that the quantity available is far less than has been previously estimated, and even with storage it will not be possible to increase the area under irrigation many times. The large river of the Territory—the Colorado, with its branches, the Green and the Grand—is practically of little use in the reclamation of the great body of vacant land on both sides. It is impossible by any known means to bring even a small percentage of the waters of this great river upon the arid lands.

The total water supply of the Territory has been estimated to be sufficient, with careful utilization and a thorough system of storage, to cultivate annually 4,000,000 acres. Of course, estimates of this character must be very general, since they depend upon a number of factors the value of which can not be accurately known until water measurements have advanced to a greater degree of completeness. Comparatively few of the rivers have been measured, and little is known as to the actual amount of water required and the proportion supplied by seepage under various conditions. Enough is known, however, to state with some degree of confidence that there is not enough water to irrigate all of the lands in private ownership, if these are so located that water can be brought upon them; but in this connection it must be stated that not all of this private land can be brought under ditch; and, on the other hand, there are thousands of acres of Government land to which water can be taken without interfering, probably, with established water rights.

Measurements of the water supply have been carried on as described in former annual reports, a few typical rivers being chosen. One of the most important series of investigations has been that by Prof. Samuel Fortier[1] upon the Ogden and Weber rivers. These water measurements have been directed especially toward ascertaining, not only the supply available at certain points, but also the increase due to seepage, or the invisible inflow from widely distributed springs. During the summer of 1894 series of observations were made upon the Ogden and Weber rivers, the points of measurement being so chosen that the total inflow for a given district could be compared with the total amount leaving the district.

The topography of the Ogden River drainage basin presents particularly favorable conditions for determining seepage. This river, which drains a portion of the northern part of the Wasatch Mountain area, flows east through a deep canyon in that range and joins Weber River a few miles above its point of discharge into Great Salt Lake. All the

[1] The Utah Agricultural College Experiment Station, Bulletin No. 38, Preliminary Report on Seepage Water and the Underflow of Rivers, by Samuel Fortier, hydraulic engineer, February, 1895.

water flowing from this upper catchment basin must pass through the rocky canyon. Water is used for irrigation in the broad valley above the canyon, and at the lower end of this canyon the river is almost completely diverted into numerous large canals. A station was established in the canyon, where observations, continued day by day, enabled computations to be made of the mean daily discharge of the river. The amount of water flowing into the upper valley by numerous creeks was measured twice during the summer season, and careful estimates were prepared, showing not only the quantity of water in these streams but also the amount which was taken out by the numerous ditches and canals. Comparing these quantities, it was found that from July to September the outflow from the valley was in general more than the amount entering by surface streams, and this was especially remarkable in view of the fact that nearly the whole of the inflow was taken by one or another of the canals and ditches, leaving

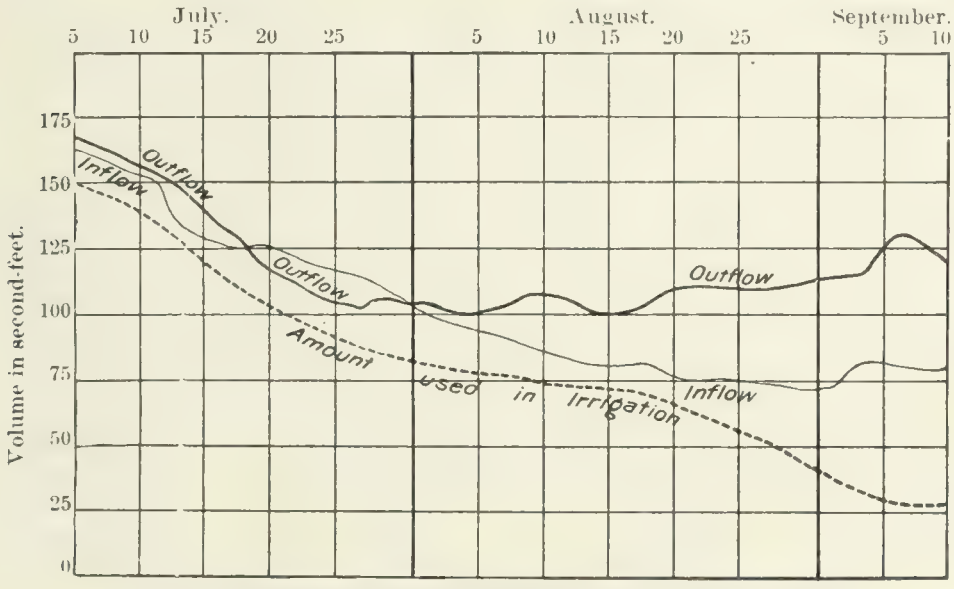


FIG. 55.—Diagram illustrating increase of water supply by seepage.

the channels of the various streams almost dry. In many instances, although the bed of a particular creek was without flowing water for some distance below the head of the particular canal, yet within a few miles water was seen, and this gradually increased in volume until there was a quantity sufficient to supply a lower ditch. At the outlet of the valley there was found flowing at all times during July an amount nearly equaling the aggregate of the inflow. In August and September this amount gradually increased until the outflow in the early part of September was nearly double the inflow.

These facts are best illustrated by the above diagram (fig. 55), in which the light line represents the quantity of water flowing into the valley and the dotted line the quantity used for irrigation. If no water returned by seepage or by percolation from the mountains, the outflow

from the valley would be represented by the vertical distance between these two lines; but the actual amount is shown by the heavy line, which by its position above the base of the drawing shows the total amount escaping into the canyon.

This information relating to Ogden Valley is valuable not so much from its local application as because this condition is typical of water supply not only in Utah but in all parts of the arid region. If no water were used for irrigation during any part of the season, it is fair to assume that during August and September the outflow of the main stream from the valley would be nearly related to the inflow through its numerous tributaries. From measurements made in other parts of the country it might be safe to assume that the outflow during these months would be far less than the inflow, and that under any natural condition the outflow would not be greater. Here, however, it is shown that the outflow far exceeds the inflow; and thus it appears that the putting of water upon the land by the many irrigating ditches tends to increase the midsummer discharge of the main stream.

This increase of water by seepage has its limitations, as pointed out in the early part of this paper (p. 471), and too great dependence must not be placed upon the value or continuity of the seepage, as more thorough methods of cultivation will undoubtedly tend to reduce the quantity thus obtainable. There are many valleys of Utah situated similarly to that of the Ogden River, and it is purposed to continue these measurements in order to ascertain local peculiarities and to obtain more definite information concerning the extent and fluctuations of the seepage waters.

Utah possesses one advantage over many other portions of the arid region, in that its principal streams are short, rise within the limits of the Territory, and can be controlled by local customs. The principal exception to this is the Bear River, which, rising in Utah, flows into a corner of Wyoming, then back into Utah, swinging across the line again into Wyoming, then into Idaho, and, crossing the southeastern corner of that State, turns back again into Utah. The elevation of the greater part of this course is, however, so great that the need of water is relatively small, but in future utilization of the river the question of water storage in Idaho for the benefit of lands in Utah will be one of considerable importance. The facilities for such storage are unusual, as has been pointed out in preceding papers.[1]

WASHINGTON.

This State, lying in the northwestern corner of the country, is probably the most humid of those west of the Mississippi Valley. Along the seacoast the precipitation is excessively heavy, and the mountains are clothed with dense forests extending inland north of the Columbia.

[1] Eleventh Ann. Rept. U. S. Geol. Survey, Pt. II, Irrigation, pp. 66-70; Twelfth Ann. Rept., Pt. II, pp. 325-334; Fourteenth Ann. Rept., Pt. II, pp. 118-121.

The vacant public land aggregates nearly one-half the area of the State (p. 478), and in addition to this over one-tenth of the land surface has been reserved for the Indians and for forestry purposes. The State is crossed by the broad land grants of the Northern Pacific Railroad Company, these covering much of the best farming land. The main body of vacant land is within the Cascade Range and directly west of the vast forest region to the north of the Columbia, and lies also out upon the broad, dry plains of the central part of the State. In the eastern end the humidity is such that wheat is raised by dry farming, the productiveness of this area being well known.

Within the tree-covered regions the water supply is large and well distributed, being often in excess of the needs of the relatively small

FIG. 56.—Clear Creek, Wyoming.

areas of the arable land. Out upon the plains of the Columbia, however, the question of obtaining sufficient water is still unsettled. Attempts at drilling deep wells have been prevented by the great thickness of the lava underlying these plains and the expense necessarily involved. The Columbia itself, although one of the largest rivers of the country, and having an estimated low-water flow of 60,000 cubic feet per second, can not be employed in irrigation, as it is bounded by bluffs and cliffs hundreds or even a thousand feet in height. The valleys west of the Columbia and immediately east of the Cascade Range, although having a very slight rainfall, are well watered by the numerous streams rising among the lofty, snow-covered summits. The principal stream of this area is the Yakima, whose waters are employed

to a small extent in irrigation. The storage facilities are exceptionally fine in the glacial lakes at the headwaters of these streams, and great quantities of water can be held at small expense for use upon the fertile lands stretching out to the Columbia. One of the most favorable opportunities for development is in this part of the State.

WYOMING.

This State as a whole is notable for its large perennial water supply, several of the important rivers of the arid region having their origin within its boundaries. In the southeastern part of the State is the North Platte River and its principal tributary, the Laramie. On the north are numerous streams flowing out of the Big Horn Mountains, among the most important of which is Clear Creek (fig. 56). To the west of these mountains is the Big Horn River itself, and in the southwestern part of the State are the headwaters of Green River. The development and utilization of these sources of water supply have proceeded slowly, and the State as a whole, owing to its high altitude, has been considered as chiefly adapted to grazing. There are, however, many valleys where the climate is similar to that of eastern Colorado and is highly favorable to the success of ordinary crops.

The vacant lands aggregate 83,644 square miles, or 85.72 per cent of the area of the State. In addition to this should be considered the Indian and forest reservations, embracing about 8 per cent. In this area of reservation has been included the Yellowstone National Park and the additional forest reserve to the east and south. A deduction from the area vacant should, however, be made to cover the lands not yet selected under the land grant of the Union Pacific Railroad. This crosses the southern side of the State and includes considerable areas of land having very small value on account of its altitude and rough, desertlike character. Probably the best farming lands in the State are those in the southeastern part, along the Platte, and on the northern border, in the valleys east of the Big Horn Range. There are, however, vast tracts of land still in the hands of the General Government, especially in the Big Horn Basin (fig. 57), to which water can be taken at moderate expense.

The difficulty of obtaining title to vacant lands lying in compact bodies has to a certain extent prevented development and retarded settlement. In recognition of this fact, which, as previously pointed out, prevails in other States, Congress passed what is known as the Carey Act. This law, approved August 18, 1894 (Stat. L., vol. 28, pp. 422, 423), gives to each State containing desert lands the right to select upward of 1,000,000 acres upon certain conditions, the principal of these being that not less than 20 acres of each 160-acre tract shall be cultivated by actual settlers within ten years. The provisions governing the selection and reclamation of these lands have, however, been

found to be of such stringent character that even in Wyoming it has not been found possible to proceed. A number of selections have been made by the State officials, and it has been ascertained that it will be practicable to reclaim large areas in various parts of the State if the act donating the land can be amended in some of its details. The total area vacant, as shown on page 489, comprises over 53,000,000

FIG. 57.—Big Horn River, Wyoming.

acres, so that even if the State should succeed in utilizing the whole of the million-acre grant this will not diminish the area of vacant public land by more than 2 per cent. The water supply, as noted above, is large, and has been estimated to be sufficient under ordinary circumstances to irrigate 9,000,000 acres, this being from two to three times the extent of the lands now in private possession.

WATER RESOURCES

OF A

PORTION OF THE GREAT PLAINS.

BY

ROBERT HAY.

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WATER RESOURCES OF A PORTION OF THE GREAT PLAINS.

By Robert Hay.

GENERAL STATEMENT.

In going westward from the Mississippi Valley the traveler by almost any route rises very gradually up a gentle slope toward the base of the Rocky Mountains. He progresses, also, from regions whose copious, evenly distributed rainfall results in a humid climate toward that part of the continent which, from its scanty, irregular precipitation of moisture, is known as the arid region. The change from humid to arid is very gradual, there being a broad belt of country several hundred miles in width which may be considered as middle ground. One year it may be called subhumid, the next arid or subarid, its condition depending upon the fluctuations of rainfall through seasons and years.

The almost boundless extent of tillable land, the ease with which large areas can be cultivated, and the wonderful fertility of the soil have attracted settlement farther and farther from the Mississippi Valley out upon the Great Plains, and even into and across the regions which from scantiness of rainfall are known as subhumid or semiarid. The tide of settlement rolling westward has been thrown back again and again by the almost insurmountable barrier interposed by the meagerness of rainfall. Individuals and communities have attempted to make homes, have invested all of their available means in enterprises dependent upon farming, and after perhaps a year or two of success, due to an unusual amount of precipitation or to a fortunate shower coming at the right time, have been compelled by prevailing droughts to abandon their possessions and scatter, almost penniless, to other localities. These men have been succeeded by others, perhaps more sanguine of success or ignorant of the fate of their predecessors, and they in turn have become disheartened by repeated crop failures. Here nature seems to have lavished her resources, withholding only one—that of an ample supply of water.

The object of this paper is to give the results of a careful investigation of the limited water supply of a portion of this fertile area and to bring out facts tending to show that the situation is not hopeless, but that by adapting his methods to the peculiar conditions the farmer may reasonably expect a considerable degree of success even where now the aspects are most forbidding; for, although little dependence can be

placed upon rainfall, it is apparent that in many localities water from underground may possibly be procured and brought to the surface. In this paper the attempt is made to answer questions as to the quantity and distribution of this water, its depth, and the methods by which it can be made available for agriculture and other purposes.

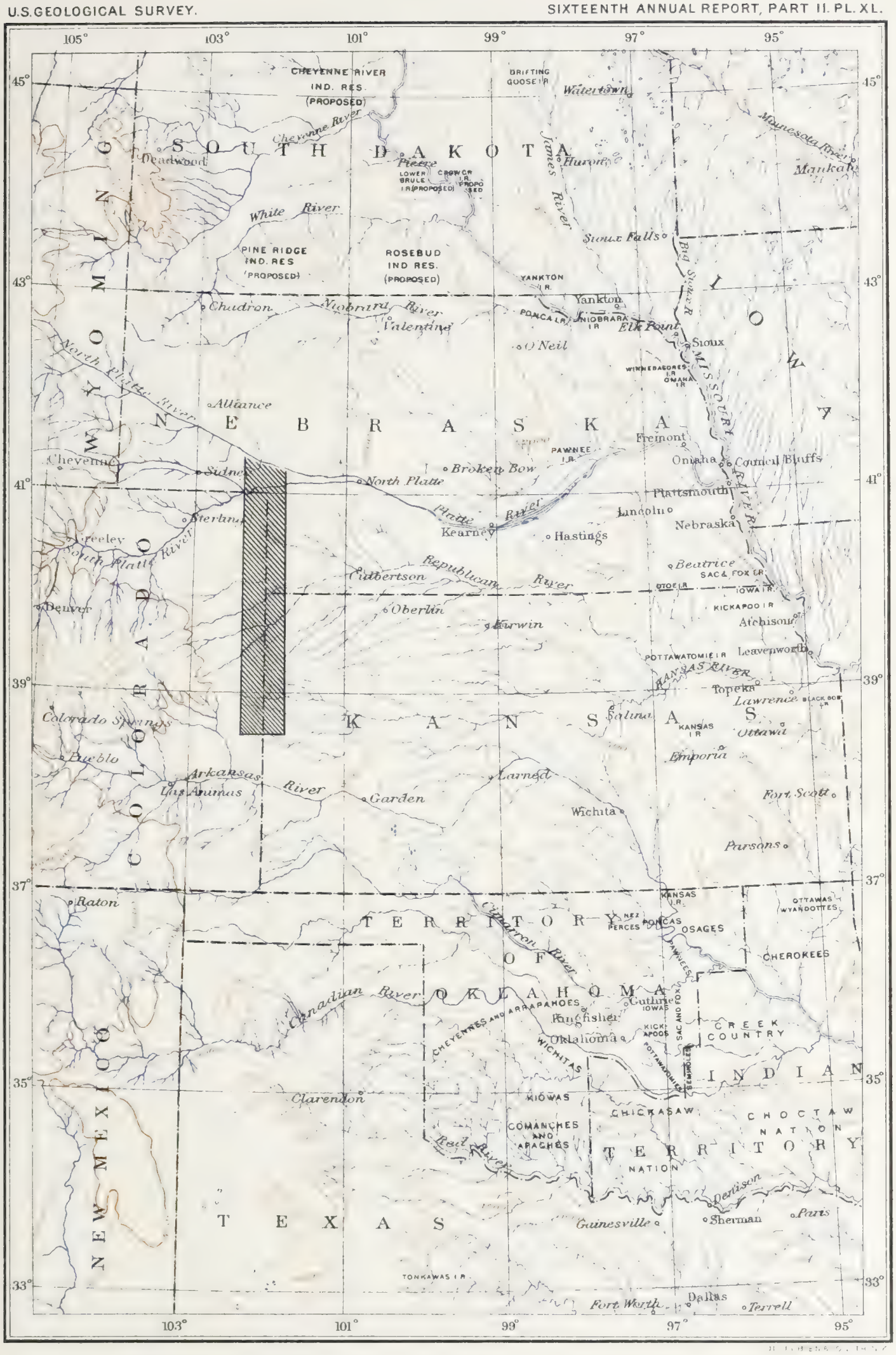
As the area requiring examination is of vast extent it was considered advisable to attempt to work during the field season of 1894 in a relatively limited district, which should, however, be as nearly typical as possible. This district, as shown by the accompanying map (Pl. XL), consists of a strip about 30 miles wide lying on each side of the one hundred and second meridian and extending from North Platte River on the north southerly to the South Fork of the Smoky Hill River. The meridian just mentioned is practically coincident with the eastern boundary of Colorado, and therefore the area covered by the field work lies within the boundaries of three States, namely, Nebraska, Colorado, and Kansas.

TOPOGRAPHY OF THE DISTRICT.

The district under consideration in this report extends from north to south through nearly 2½ degrees of latitude. Its area is between 5,000 and 6,000 square miles and it includes parts of three counties of Kansas, five counties of Nebraska, and six of Colorado. It is a typical district of the Great Plains. There is considerable elevation, yet there are no mountains. The highest part on the one hundred and second meridian is about 4,000 feet above sea-level. West of that there is increment of elevation; eastward the altitude is less. There are several valleys running in a general easterly direction across the strip. The sides of these valleys and the lateral dales are often rugged with profound canyons. One of these valleys is that of a mountain river—the South Platte—and the northern limit of the district includes the slope to the North Platte, also a mountain river. The other valleys all belong to rivers of the plains, in which they have their source and course, not being fed by mountain snows. These east-west valleys, in order from the north, are as follows: North Platte; South Platte; Frenchman; Republican, North Fork; Republican, Middle Fork (Arikaree); Republican, South Fork; Beaver Creek (three forks); Sappa Creek; Smoky Hill River, North Fork; Lake or Turtle Creek; Goose Creek; Smoky Hill River, South Fork; Eagletail Creek; Rose Creek.

There are some others of less importance, which will be referred to in the course of the report in their proper relations. Some of these river beds have no water in them in the territory investigated, and some of them begin to have water in this region, being dry arroyos farther west.

The North Platte always carries some mountain water, which is augmented a little by springs in its plains canyons. On October 11, 1894, it was carrying 609 second-feet of water, as ascertained by measure



SHOWING GEOGRAPHIC LOCATION OF AREA EXAMINED

Scale.

0 50 100 200 300 STAT. MILES.

ment at a point north of Ogallala.[1] This was about the quantity then flowing at Orin Junction, Wyo., indicating an inflow from plains springs to compensate for the evaporation during the long journey. The South Platte had no water during the period of the investigation in its neighborhood in October. The Frenchman has its first surface water almost exactly on the one hundred and second meridian, and a few miles east it becomes a permanent stream. The North Fork of the Republican had running water in October, but not the Arikaree, and the South Fork had but little. These streams usually rise at this time of the year, but in 1894 they were delayed a month. The beds of Beaver creeks are dry in this region, receiving water at points 30 miles east. The North Fork of the Smoky has no water at the meridian mentioned above, but is running a small stream at the east limit of the district. Lake Creek and Goose Creek have only pools, except at times of heavy rains. The South Fork of the Smoky is the same, and also Eagletail Creek, but Rose Creek flows perennially. All of the river valleys, however, have water under the sand or gravel of their beds at the depth of a few feet under the alluvial bottom lands.

The parts of the region not included in the river valleys—the interfluvial spaces—constitute the plains proper. They are spoken of locally as "the table" or "the table-land." They are mostly gently rolling, with level reaches and shallow inclosed basins. These basins are often in lines, one end of which is the beginning of what is locally known as a "draw," that gradually widens and deepens into a dale or canyon tributary to the main river valley to the north or south. There is a general slope eastward, and there is also on all the plains a slight slope southward.

Beginning at the North Platte and ascending from its valley up the rugged canyons to the plain southward, the traveler suddenly emerges on the smooth prairie—the table—the long southerly slope of which is apparent. It is seen at any point east or west of this for scores of miles. The easterly trend of topographic features is also noticeable, and at two places, one the head of Eagle Canyon and another several miles east, these are marked phenomena, the southeasterly valley being a broad, smooth depression in the upland prairie. The depression from Eagle Canyon is so conspicuous that a driver described it to me before I saw it by saying that "Eagle Canyon runs through the divide from river to river." The one northwest from Ogallala is as marked, but it goes out from the side, not the head, of its canyon. As soon as one reaches the prairie from the north ravines the scene suggests that some enormous planing machine had gone over the surface and that the southeast depressions are grooves made by its tool.

On the south of the South Platte in Colorado the same phenomena are presented, but as we go east in Nebraska the southeastern slope is not so conspicuous, being hidden by the sand hills. South of the Frenchman the southeastern slope is not discernible by the eye, as

[1] Bull. U. S. Geol. Survey No. 131, pp. 28–30.

the whole region, extending from a mile or two south of that river to the Republican, is also occupied by sand hills. This arenaceous area is at least 1,000 square miles in extent, lying in both States.

This southeastern slope of the smooth prairie, with lines of basins and long drains in the same direction, is characteristic of the whole region from the top of the breaks of the North Fork of the Republican (south of Wray or Laird, in Colorado) to the Arikaree; also from the Arikaree to the South Fork; from the South Fork to the Beaver; from the Beaver to the Smoky; and from the North Fork of the Smoky to the South Fork, and also for the smaller plateaus between creeks.

Notwithstanding this southeastern slope of each separate plain, there is a slight increment in the elevation of the whole district southward. The North Platte Valley is the lowest of them all; that of the Smoky the highest. The divide between the two Smoky forks on the one hundred and second meridian, near the head of the draws of Goose Creek, appears to be the highest land in Kansas. (See Pl. XLII.)

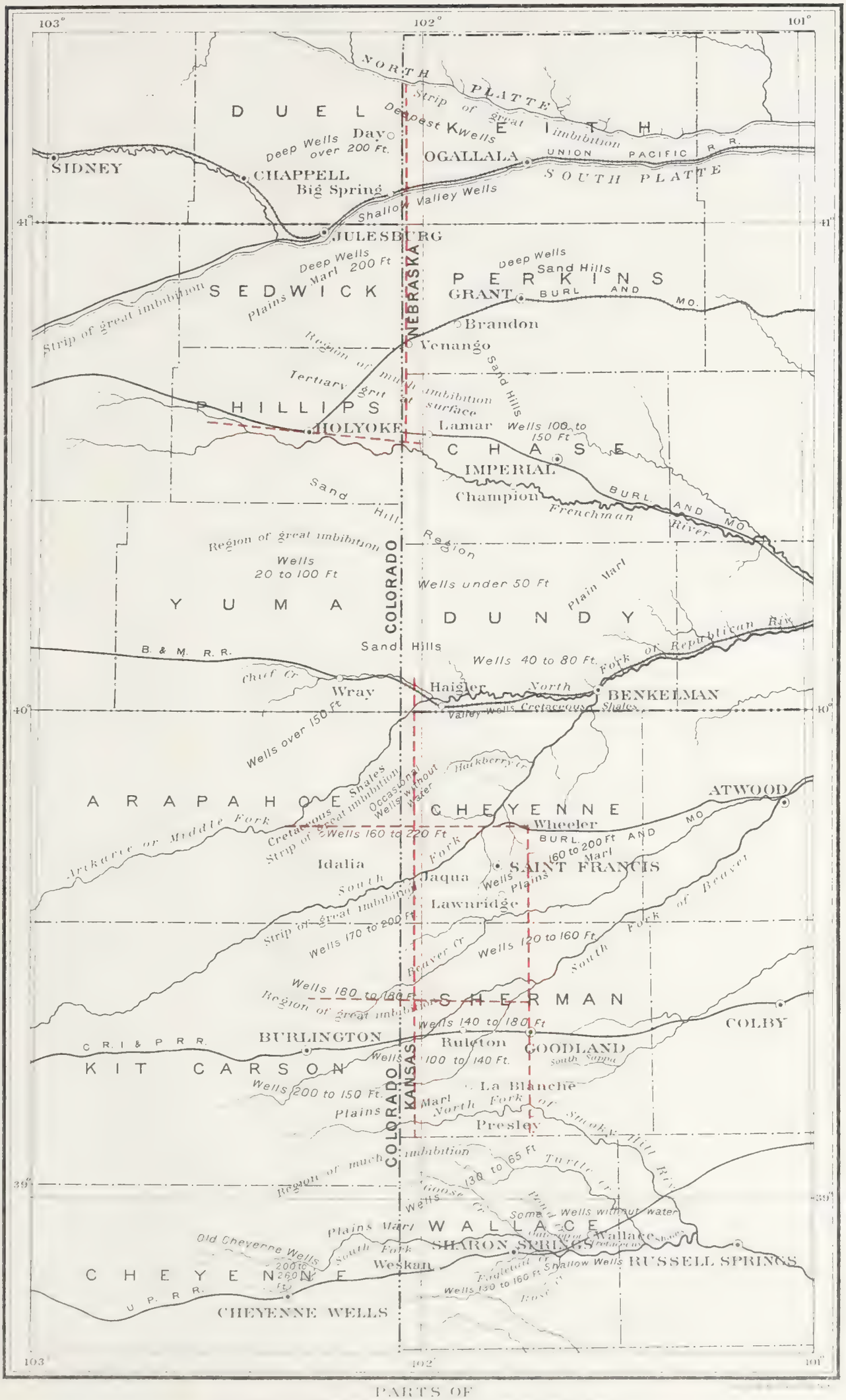
There are great differences in width of bottom lands of the different valleys. The two Plattes have the widest, because they are farthest from the headwaters of the streams. The Republican forks come next. The Smoky bottoms and those of the Frenchman and of Lake Creek have about the same width. Just north and east of Sharon Springs the South Smoky bottom is nearly a mile wide.

The topography in general may be considered in the three parts: (1) valley bottoms; (2) valley slopes; (3) interfluvial plains. The principal features of each have been pointed out. Some other details will be given in illustration of particular subjects further on.

There is an important cultural feature of the topography of the selected district. Five railways cross it from east to west, namely: the Union Pacific, in the South Platte Valley; the Burlington and Missouri River, on the Platte-Frenchman divide; another division of the same road, in the Republican North Fork Valley; the Chicago, Rock Island and Pacific, on the Beaver-Smoky divide; and the Union Pacific (Kansas Division), on the Smoky-Whitewoman divide. A branch also of the Burlington and Missouri River Railroad runs up the Republican South Fork nearly to the meridian.

Besides the elevations above sea-level which are given on the profiles illustrating this report, the following table will assist in giving a general idea of the altitude of the country, both on the table-lands and in the valleys. The figures are taken partly from Gannett's Dictionary of Altitudes,[1] but mainly from a table furnished to the writer by the engineers of the Burlington and Missouri River Railroad. The arrangement is that of the places going west on the several lines of railway. The first three and the last four are on the lines of the Union Pacific; 16 to 19, inclusive, are on the Chicago, Rock Island and Pacific; and the rest are on the several lines of the Burlington and Missouri River Railroad.

[1] Bull. U. S. Geol. Survey No. 76.



PARTS OF

KANSAS NEBRASKA AND COLORADO

SHOWING DEPTH OF WELLS AND OTHER FEATURES BEARING ON THE WATER SUPPLY

BY ROBERT T. HAY

Red lines indicate profiles shown in plate

SCALE

Table of altitudes.

Place.	Altitude.	Place.	Altitude.
	Feet.		*Feet.*
1. Ogallala, Nebr	3,217	13. Wheeler, Kans	3,481
2. Big Spring, Nebr	3,361	14. St. Francis, Kans	3,288
3. Julesburg, Colo	3,468	15. Jaqua, Kans	3,500
4. Grant, Nebr	3,405	16. Goodland, Kans	3,687
5. Venango, Nebr	3,588	17. Ruleton, Kans	3,788
6. Holyoke, Colo	3,734	18. Kanorado, Kans	3,906
7. Imperial, Nebr	3,278	19. Burlington, Colo	4,163
8. Lamar, Nebr	3,516	20. Wallace, Kans	3,303
9. Benkelman Nebr	2,968	21. Sharon Springs, Kans	3,419
10. Haigler, Nebr	3,258	22. Weskan, Kans	3,803
11. Wray, Colo	3,512	23. Cheyenne Wells, Colo	4,279
12. Akron, Colo	4,650		

HYDROGRAPHY OF THE DISTRICT.

This region, though semiarid, has supplies of water that may be used to supplement the precipitation of the seasons. These supplies may be considered under two heads: first, the visible or surface waters; second, the invisible subterranean waters. The visible waters may be again divided into lakes, streams, and springs.

LAKES, STREAMS, AND SPRINGS.

Lakes exist only in years of more than average rainfall, when the channels of old river beds in the valleys become oblong pools and the numerous basins on the upland plains become shallow ponds from 1 to 40 acres in extent.

All of the valleys have running water in them during some part of the year. The North Platte always carries water coming from the mountains; the South Platte, only after the irrigation season is over in the region just east of the foothills of Colorado. The Frenchman has its first water from springs just at the one hundred and second meridian. East of that it has a perennial flow. The North Fork of the Republican in this region has running water all the year round at its upper part, which becomes lost in the sands below for part of the year. The Arikaree and the South Fork have water in the winter months, not from winter rains, for there are none, but, as is generally believed, because then there is not the evaporation which in the hot months licks up the flow from the cool pools that mark the presence of springs. Neither fork of the Smoky has water at the one hundred and second meridian, but spring pools and water under the bottoms are abundant and numerous east of this point. The Beaver arroyos are all dry, with water under the red gravel, as are the Upper Frenchman and the Smoky Forks in Colorado.

There have been no continuous measurements of the flow of any of the streams of the district. On October 11, 1894, as has been before mentioned, the North Platte north of Ogallala was found to be carrying 609 second-feet. This flow increases in early summer to thousands of second-feet. The South Platte, whose bed, over half a mile wide, is usually a waste of dry sand, in June, 1894, floated flatboats that car-

ried down a contingent of the Coxey army. The Frenchman above Champion supplies an irrigation ditch made last year, and eleven ditches operating in the valley of the South Fork of the Republican in Kansas have filed on from 800 to 1,000 second-feet from that river and its underflow. At Presley, on the North Fork of the Smoky, Mr. Lancaster has filed on 3 second-feet, which is probably above the average flow, and below there the water disappears again in the sand. Rose Creek, which gives first permanent water to the South Fork, has been found to give 6 feet perennially. All the water of these rivers of the plains comes from springs issuing from the beds of the Tertiary grit, and some of the water of the mountain rivers also comes from the same source.

While there is much spring water in this region, there are few copious springs. It may be said that there are none in the North Platte Valley, there being only a few places in its long canyons where water is at or near the surface. On the south side of the divide between the Platte rivers there are very few outlets of running water. At Big Spring is the only one at all approaching copiousness, and this would probably yield more if it were cleared out.

The slope on the south side of the South Platte is different from that on the north. It has been noticed that it is exceptionally smooth as compared with south sides of other valleys, though the hummocky gravel hills form a conspicuous feature. It is exceptional in this also, that from some miles west of Ogallala to beyond Julesburg, in Colorado, there is a series of springs in ravines on this slope. They are as follows:

a. Spring near north line of Perkins County, Nebr., 2 miles from the Colorado corner.

b. State Corner Spring, half mile from northeast corner of Colorado, in Nebraska.

c. Harris Spring, 3 miles west of State corner, in Colorado.

d. Spring a mile or two west of Harris's and 4 miles south.

e. Spring at a ranch 2 miles west of *d*.

f. Spring in the Italian Cave, 2½ miles southwest of Julesburg, sec. 4, T. 11 N., R. 44 W.

g. Spring 3 miles south, near head of the Italian Ravine.

h. Springs on sec. 15, T. 11 N., R. 45 W., at Anderson's, 5 miles west of Gibello's ranch.

These springs are at different altitudes, indicating different water levels. Springs *b*, *c*, and *h* are at the lowest levels. They come out near the bottom of the gravel beds or below, only a little above the higher bottom lands of the Platte Valley. Springs *d*, *e*, and *g* are within 60 or 80 feet of the top of the high prairie southward; *a* is between the extremes of elevation above the valley. Spring *f* is really an artificial spring, not far above the river level (32 feet). It is in a cave dug out by an Italian named Gibello. It is in fine conglomerate, which seems dry all around, but this little hollow, at the side of the main passage of the cave, always has water in it at a temperature of 48° F., the air of the cave being 54°.

This long line of springs on the south side of the Platte Valley suggests a dip of the strata different from that given above as the prevailing dip of the region. It is, however, different only in appearance. Every one of the springs (Gibello's excepted) is sufficiently far up a ravine to have some gravelly outcrop and mortar bed to the west and northwest of it. In every case the spring is on the west side of the ravine. The flow of these springs confirms rather than discredits the statement as to the general dip of the region. They also illustrate the water-bearing value of the gravel or conglomerate beds of the Tertiary grit. They show that there is water even where the area *up* the dip-slope from the springs is comparatively small. Springs *a*, *d*, and *g* supply water to many settlers on the high prairie, where the wells are deep. None of them can be called copious. The only one (*c*) whose measurement I was able to obtain gave 4 gallons per minute. It, however, supplies a small reservoir from which some irrigation has been done.

There are no springs, properly so called, on the Frenchman. The outcrop of the water-bearing strata allows water to ooze rather than run, and the total flow is considerable. On the North Fork of the Republican there are small perennial springs east of Benkelman, and at Nesbits and Rock Creek, farther west, there are springs from the grit back in the sand hills. West of Wray the perennial flow of Chief Creek comes from the same source. These are all on the north side of the main valley. Here the shales are at the surface, and in some places the water seems to flow out of them, but it really comes from the gravel of the grit and soaks the clay shale, or descends in cracks only a short distance.

Some springs of considerable volume are in ravines on the north of the Arikaree, but always beneath the grit and above the shale. Horse Creek and Wolf Creek are spring fed, running all the time, and irrigation is done by them at the Rosenkranz ranch. Farther west there are springs on the south side. On the Repubican South Fork, nearly as far west as Flagler, the so-called Crystal Springs come from the top of the shale under the conglomerate on the north side of the river bed; near St. Francis some spring pools in ravines on the south side supply water for considerable irrigation. In the beds of the Smoky forks water of the alluvial underflow is forced to the surface in pools by the presence of shales, and occasionally a small run of water at a higher level on the slope testifies to the presence of the water-bearing strata above the outcropping shales.

The time at which this investigation was made—October and November, 1894—was suitable for estimating the continuous value of the visible water of the region. This was the dryest year since 1880, and no so-called wet-weather springs were seen. Up to October only 4½ inches of rain had fallen at Imperial, Nebr.; to the end of November, only 7½ inches at Wallace, Kans.; yet the Frenchman and Rose Creek had their rushing perennial flow.

UNDERGROUND WATERS.

The underground water may be considered under two heads: first, the underflow of the valleys, and second, the sheet water of the highlands. The sandy character of the alluvium of the valleys allows considerable underground storage of water. Wells from Julesburg to Ogallala, in the South Platte Valley, get abundance of water on the lowest bottom lands at from 10 to 20 feet depth. Occasional beds of clay separate the water into two or three sheets, which coalesce into one thicker vein around the edges of these clay deposits. Where there are more veins than one the waters in the lower ones usually rise to the level of the highest when a boring reaches them. Under the second bottom land the water is found at depths of from 25 to 50 feet, the greater depths being mostly farthest from the river bed.

The water under the second bottom is, as a rule, a part of the same sheet and in the same kind of alluvium as that under the first bottom, but sometimes the first bottom is a sheet of the Plains marl, in which case the water under it is in unaltered Tertiary grit or in débris of the grit, which is the alluvium of the mid-Neocene erosion. In either case there is abundance of water. Julesburg has a railway well and 16 other wells. Big Spring has 8 windmill wells and 16 worked by hand pumps, and Ogallala more. In no case does the putting down of another well appear to affect the old ones. The North Platte Valley has only a few wells on its bottom lands, but it is probably as well supplied with water as its southern neighbor. The great depth of the alluvium in both these valleys indicates the presence of a large body of stored water. The prevalent opinion that this water has a motion in the general direction of the river is probably correct. This underflow will be discussed later. It is to be understood that the water beneath the bed of the rivers is included in this flow, as well as that under the bottom lands. The available width of the South Platte Valley, then, as a storehouse of water can not be less than a mile and a half, on the average, throughout the region examined, and in parts it is much more. Every valley in the district has this underflow. The Republican forks have the area and depth restricted by the presence of the shales, and it would take an actual survey of every mile of the valley land to determine the exact amount underlain by the water. Still, the three forks probably average half a mile wide for their total length in the district—90 to 100 miles. The valley of North Smoky Creek is narrower, but for 20 miles it may have an underflow a quarter to three-eighths of a mile wide. The South Fork averages fully half a mile in width for its 35 miles in the district. The Beaver valleys can scarcely be said to have an area of underflow outside the bed of the arroyo, which is only 10 to 30 feet wide; still, water is there in the red gravel, as in the upper reach of the Frenchman.

Water available for man's use on the high prairie in this district may be drawn from wells. One or two long ditches are in process of mak-

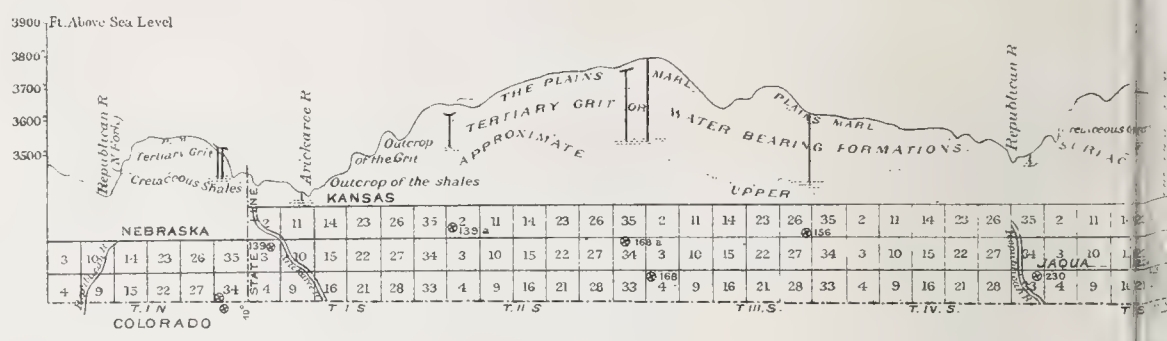


FIG. 1. GEOLOGICAL SECTION AND PLAT FROM NORTH FORK

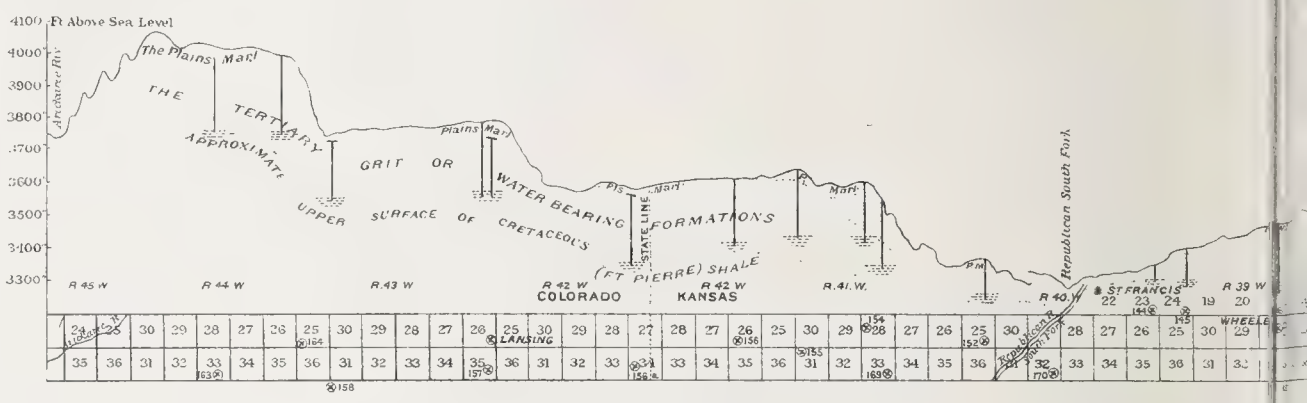


FIG. 2. GEOLOGICAL SECTION AND PLAT, FROM SHIELDS SPRINGS COLORADO, TO WHEELER, CHEYENNE CO. KANSAS

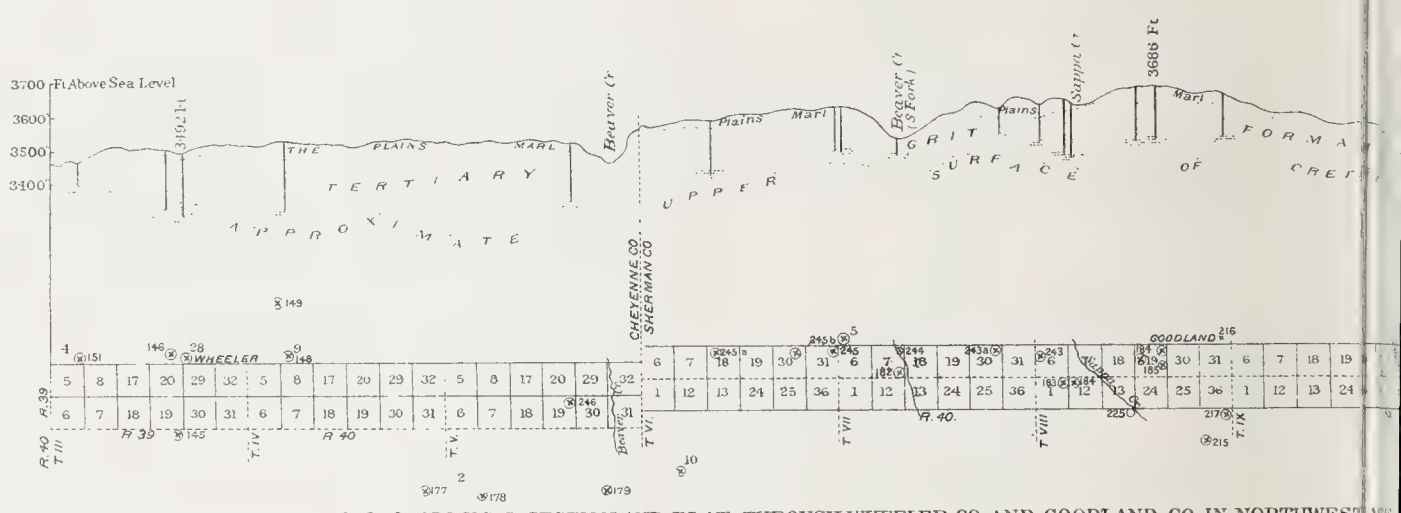


FIG. 3. GEOLOGICAL SECTION AND PLAT THROUGH WHEELER CO, AND GOODLAND CO. IN NORTHWEST

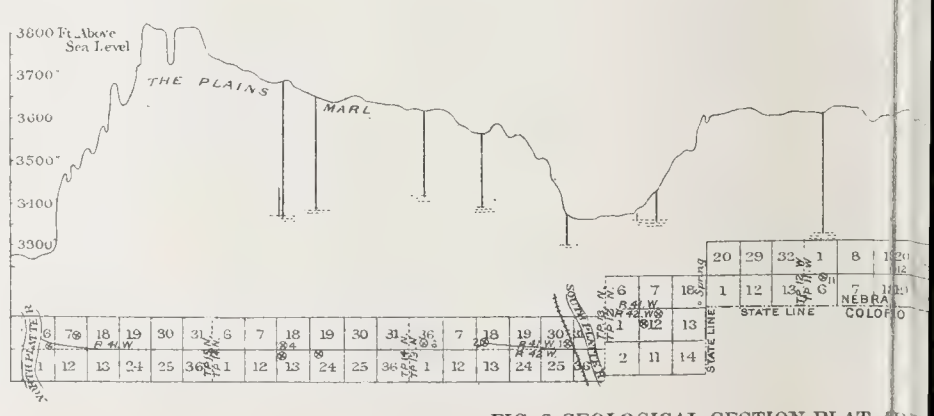


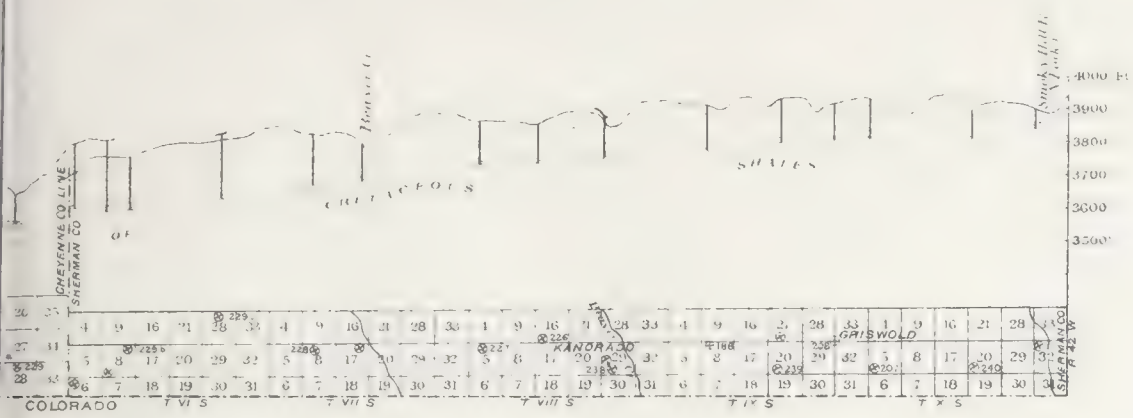
FIG. 6. GEOLOGICAL SECTION, PLAT AD

GEOLOGICAL SECTIONS AND PLATS SH

FIGS. 1. 2. 3. AND 4. BY ROBERT

Horizo

36 0



EPUBLICAN RIVER TO NORTH FORK OF SMOKY HILL RIVER

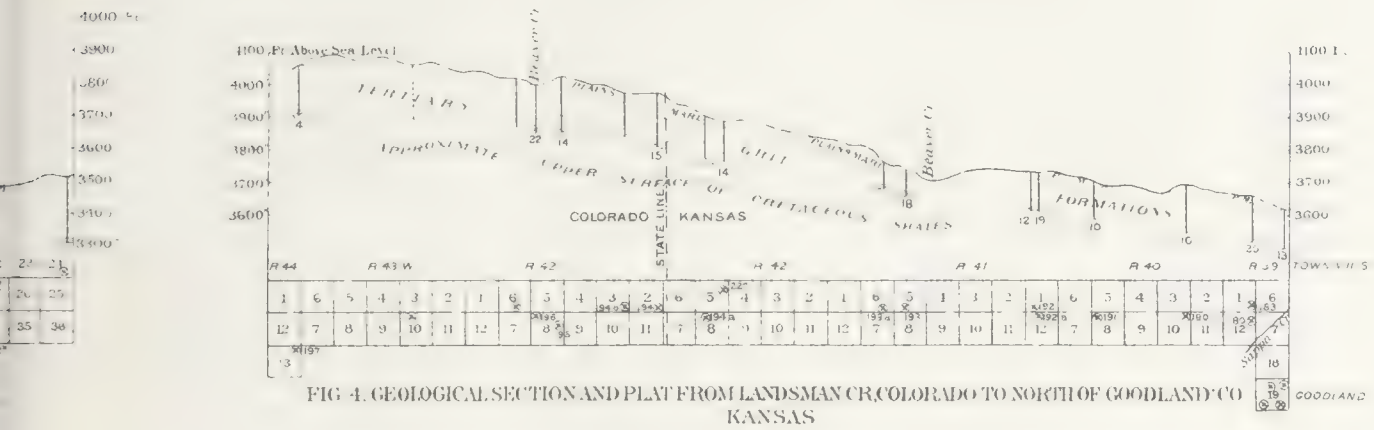
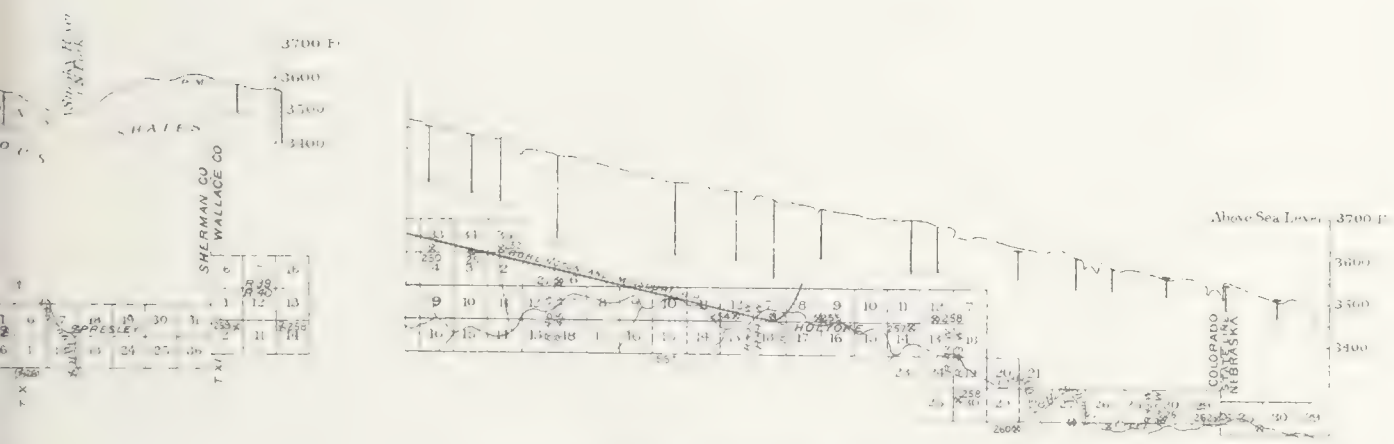
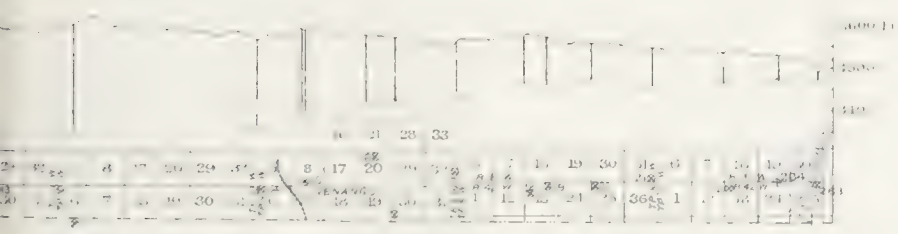


FIG 4. GEOLOGICAL SECTION AND PLAT FROM LANDSMAN CR, COLORADO TO NORTH OF GOODLAND CO KANSAS



SAS.

FIG 5 GEOLOGICAL SECTION PLAT AND PROFILE ON THE FRENCHMAN RIVER



PROFILE OF BIG SPRING LINE

NOTE ELEVATIONS FROM BAROMETER COMPARED WITH RAILWAY LEVELS. WELLS MARKED THUS ⊕

ING WATER-BEARING STRATA AND WELLS

Y. FIGS. 5 AND 6. BY W.W. FOLLET.

l Scale.

ing, by which it is proposed to bring the surface water and the underflow of the valleys onto the highest land of the divides. That water will be thus obtained in sufficient volume to reach the high land at the extremity of the ditches can be demonstrated only by actual performance. Frequent tapping of the underflow would probably furnish water enough in short ditches to supply lands at less height than the body of the table-lands.

The water-bearing strata under the high lands are as thoroughly saturated with the desired fluid as most of the alluvium of the valleys. All this water must have a flow in the general direction of the dip of the strata containing it. Its overflow is the running water from springs. When we compare the depth of wells on any given table-land and find, as is illustrated by the profiles accompanying this report (see Pl. XLII),[1] that the water in them stands at about one level, it is

[1] Below is a list of the wells shown on Pl. XLII and described in Bull. U. S. Geol. Survey No. 131. The first column gives the numbers used on Pl. XLII; opposite these are the numbers for the same wells as used in Bulletin No. 131, and the pages thereof on which the descriptions are to be found.

Plate XLII. Well No.	Bull. 131. Well No.	Pages.		Plate XLII. Well No.	Bull. 131. Well No.	Pages.	
FIG. 1.							
139	4	114	116	226	79	115	123
168*a*	27	114	118	238	84	115	123
168	6	114	116	188	93	115	124
156	2	114	116	239	73	115	122
230	11	114	117	208	74	115	122
229	10	114	117	207	71	115	122
228	81	115	123	240	72	115	122
227	80	115	123				
FIG. 2.							
163	5	106	108	152	30	115	118
164	4	106	108	170	25	114	118
158	7	106	108	144	34	115	119
157	8	106	108	145	35	115	119
156*a*	9	106	108	146	36	115	119
156	2	114	116	147	38	115	119
155	3	114	116	192	62	115	121
154	29	114	118	145	35	115	119
169	26	114	118	146	36	115	119
FIG. 3.							
148	39	115	119	244	59	115	121
149	41	115	119	243	60	115	121
177	12	114	117	183	67	115	122
178	40	115	119	184	66	115	122
246	14	114	117	185	94	115	124
179	28	114	119	215	53	115	120
245	58	115	121	217	50	115	120
181	69	115	122	216	51	115	120
182	68	115	122				
FIG. 4.							
195	33	106	110	192	62	115	121
196	32	106	110	191	63	115	121
194	35	106	111	190	64	115	121
227	80	115	123	183	67	115	122
193	85	115	123	180	70	115	122
FIG. 5.							
260	55	115	121	259	97	116	124
261	54	115	120	258	112	116	126

perfectly justifiable to speak of the sheet water of the plains. It will be seen by these profiles and the well records that the depth to the sheet water varies somewhat on the same table-land, and more on different table-lands. There are two causes for this, viz, (1) irregularity in the structure and varying thickness of the water-holding rocks, as will appear later, under the heading Topography of the Tertiary Grit, and (2) the depth of the river valleys bounding the particular table-lands. The Frenchman and the Beavers, and the western part of the Smoky Forks, are not bounding valleys; they are merely depressions in the table-lands.

Noting all the above exceptions, it will be remarked that the water level of the wells of the plateaus is a little higher than the level of the bounding valleys, which act as drains to the superabundant sheet water of the highlands. The height at which it is held depends on the irregular porosity of the water-holding beds, and also on the fact that the water is frequently sealed in the edges of the plateau by the overlapping beds of the Plains marl or by infiltration into the edges of the porous beds of the argillaceous particles from the clay débris of the marl or of the grit itself.

The abundance of this sheet water is proved by the numerous wells in all the towns on the plains, some of them being railway or city corporation wells operated by steam pumps, as at Goodland, Burlington, Cheyenne Wells Holyoke, Grant, Ogallala, and Julesburg, and also by the numerous wells outside all municipalities. Upward of three hundred wells of all kinds have been examined in this investigation, and probably twice as many have been passed by. The further discussion of the subject under different heads will, it is believed, fully establish the probability that the wells of the region may be multiplied many times and their contents drawn upon much more continuously than at present before any signs of a limitation of the supply will appear.

SOURCE OF THE WATER SUPPLY.

GENERAL CONDITIONS.

In discussing this subject I have often remarked that the origin of this supply is of comparatively small importance to the people of the region. It is of course interesting, as a matter of scientific inquiry, and the inquiry has an economic bearing so far as it relates to the possibility of exhausting the source of supply.

It is a trite saying that the water of the land comes from the air. Three thousand years ago the circulation of moisture had been observed. The evaporation from the sea, the winds blowing the vapors inland, the precipitation as rain and snow, the running off as springs and rivers back to the sea—all this has been known for ages. The inquiry limits itself to the question whether the water supply with which we are dealing has its origin in a near or distant aerial precipitation. Is it entirely

dependent on the rainfall of the plains, or is it assisted to a greater or less degree by precipitation in the mountain region to the west? Do the rivers of the mountains bring any water to the plains? and does underground percolation from the mountains supply any part of the sheet water under the plains generally or under that portion of them included in this investigation?

It has already been stated that of the two Plattes, both mountain rivers, only one has mountain water in it in this region of the plains for the whole of the year. It is, however, doubtless true that some mountain water is found in the underflow of both the Platte valleys all the time. From what has been said of the thickness of the sandy water-bearing alluvium, it may be assumed that this water is a large factor in the valley supply. The ready absorption of the local rainfall by this alluvium also suggests that this must be an important source of these underflow waters. That the waters of these river beds supply any part of the subwaters of the high prairie can not be believed. An inspection of the Frenchman and Big Spring profiles, made by Mr. W. W. Follett[1] (see Pl. XLII, figs. 5 and 6), will show that the relative levels of waters are not such as would be expected if the rivers supplied the plains. On the other hand, it may be affirmed that these larger river beds, as well as those of the plains rivers, act as drains, carrying away a portion of the subwater of the highlands.

In the matter of percolation of water from the mountains to the beds containing the sheet water of the plains, there is a more definite answer. The geological conditions seem to make it impossible that this source should even partially supply the sheet water, as the Tertiary beds containing it nowhere (except in one place, elsewhere mentioned) come in contact with the mountains. There is a deep trench of river valleys along the east front of the mountains, which effectually prevents any flow of water either under or above ground from the mountains to the formations holding the sheet water of the plains. We are forced, then, to the conclusion that the sheet water of the plains is supplied by the rainfall of the plains.

Owing to the eastward and southward slope of the surface, and the similar dip of the subjacent rocks, we infer that there is a slow eastward direction of the subterranean percolation, and that therefore the sheet water at any particular place has reached that place from some distance to the north and west of it. How far it has come it is not possible, with our present data, to say. Whether the knowledge would be of much value is doubtful.

This statement that the subwaters originate in the local rainfall is looked upon by some as necessarily implying a very small supply, while an assertion that this water comes from the mountains is looked upon

[1] The final report of the artesian and underflow investigation and of the irrigation inquiry: Senate Ex. Doc. No. 41, Fifty-second Congress, first session, Part II, p. 22 (Frenchman line), p. 23 (Big Spring line).

as implying the continuance of a bountiful supply. This is entirely a fallacy. The rainfall of the mountains is not measured by the depth of the snowdrifts in sheltered valleys. Fifty feet of snow would represent, for the area where it is found, 60 inches of rainfall. But the mountain areas we are dealing with have no such amount of precipitation. The rainfall at Pikes Peak is only 29 inches. The whole Front Range has less than eastern Kansas or eastern Nebraska. The rainfall on the one hundred and second meridian may be taken to average 18 inches, decreasing westward, and though the evaporation is very great in this region in the summer, yet the conditions for imbibition by the soil and rocks are also highly favorable over considerable areas. The writer believes that the sheet water of the plains will maintain its quantity perennially, and that it will not show diminution under any drain that is likely to be put on it for a generation. Some of the facts already given, with others yet to be mentioned, warrant this opinion.

There is an opinion prevalent among the settlers on the plains that this sheet water, located, as has been already described, in the porous Tertiary beds, forms a continuous sheet from north to south as well as from west to east. But this is true only to a very small extent. The great valleys effectually cut off such connection of the sheet waters. The various forks of the Republican in the region of this investigation divide from each other the waters of their included table-lands. In these examples the fact is easily seen, as the valleys are cut down into the shales much below the level of the sheet waters. The parts of the region drained by the Beavers and the North Smoky, however, can be considered as having a continuous sheet of water, as the valleys have not been cut to the level of the water. Farther east the portions of the plain between these streams have their separate sheets of water. An examination of the well profiles will establish beyond a doubt this break of the water levels.

The great body of the sheet water of this region, and of most of the Great Plains, as we shall show further on, is held in the porous strata of the Tertiary grit. Where the grit is thick little or none of the water is in the upper beds. The controlling factor as to the depth of the water in the grit seems to be the depth of the drainage valleys. The water is somewhat higher than their level. If these valleys cut through into the Cretaceous beds, as in the Republican forks, the water rests on the shales or saturates them to a small depth beneath the grit.

Besides these, another factor determining the depth of the wells is the thickness of the Tertiary marl on the top of the grit. If the grit is thick and the marl is thick, then the wells are very deep. These facts are illustrated on the maps and profiles. In that part of the plateau between the two Plattes lying within the district of this investigation both the formations are very thick. The deepest wells are along the northern edge of this plateau.

REGIONS OF IMBIBITION.

The plateau on which the Frenchman makes its shallow mark has the largest area uncovered by the marl. The porous grit here exposed and its own sedimentary soils, almost as porous, and the porous sand hills resting on this plateau, combine to make this region a most certain source of subterraneous water supply. When rain comes it is almost all absorbed. The surface imbibes it and the pores below carry it down to the storehouse beneath. Evaporation gets a relatively small part of this water. The heaviest storms rarely raise a stream in the gullies. The Frenchman has never been known to have a flood, yet its flow is constant. At the surface in this region the imbibition of the spring rains is such that the water is passed by steady percolation to the beds below, and the springs of the Frenchman, the Stinking-water, Chief Creek, and Rock Creek show a steady outflow.

The district along the meridian between the South Republican and North Smoky has also large areas where the grit is at the surface, and the slopes of all the Beavers are the same; so here are conditions favorable to large imbibition from the rainfall and constant supply of the wells, not only on the spot, but farther down the eastward slope under a slight covering of the Tertiary marl.

The exposures of the various forms of the grit in the broken districts on the north side of each plateau also constitute a region of imbibition where, notwithstanding steeper slope to the neighboring valley, much of the rainfall must be absorbed and passed into the porous strata under the plateau. In particular this must be true of the slopes on the right bank of both the Arikaree and the South Fork of the Republican, as in the region examined the troughs of those streams are for considerable distances almost at right angles to the general direction of the dip of the strata of the water-bearing formations.

The relative absorptive power of samples of the grit and other rocks of this region has been determined by Prof. Milton Whitney, of the United States Department of Agriculture. The following statement gives the percentage of moisture taken up by specimens of rock examined by him:

Amount of moisture absorbed by rock specimens from Kansas, Nebraska, and Colorado.

	Per cent of weight.
1. Grit from top of Italian Cave, 2½ miles southwest of Julesburg, Colo	3.5
2. Grit, old Cheyenne Well, Colo	3.8
3. Mortar grit above the spring at Big Spring, Nebr	4
4. Grit from the 20-foot section of Chimney Rock Canyon	4.1
5. Agatized mortar bed, McAllaster, Logan County, Kans	4.3
6. Pink "magnesia" just over the red clay 6 miles west of Julesburg, Colo	5.4
7. Rougher "magnesia" from bluff north of Ogallah, Kans	5.8
8. Conglomerate from the upper cave, Italian Canyon, Colo	6
9. Mortar bed, with agatized parts, Colo	6.2

	Per cent of weight.
10. "Magnesia" from railroad cut east of Venango, Perkins County, Nebr	6.6
11. Mortar-bed grit, south side of Beaver Creek, 1 mile southeast of Kanorado, Kans	7.5
12. Hard limestone of the Tertiary grit, Italian Canyon, Colo	7.9
13. Mortar bed (no locality given)	11
14. "Magnesia," upland outcrop, Deuel County, Nebr. 5 miles east and north of Chappell	11.2
15. Tertiary grit northwest of Ogallah, Kans	12.4
16. Turtle shell and nodules from Italian Canyon, Colo	15
17. "Magnesia" with fossil shells, SW. ¼ sec. 20, T. 6 N., R. 41 W., 6 miles southwest from Lamar, Nebr	28

Three of the samples crumbled and went to pieces when immersed in water: (1) a sample of soft "magnesia" from the mortar beds from the middle of the vertical section of Eagle Canyon, Colorado; (2) pink grit below hard limestone, Italian Canyon; (3) Tertiary grit from bottom third of Italian Canyon.

The region where the marl covering is abundant is more subject to floods in the smaller valleys, for in the larger ones the water is sometimes absorbed by the alluvium, but farther east, where rainfall is larger and the exposure of the Cretaceous formations greater, the floods pass on to do damage all the way to the Missouri River. The fact that the marl, with its smooth buffalo sod, throws off the water of rainfall rather than absorbs it, points to a method of artificially retaining this water. The marl is good material for the construction of dams, and there are along every draw numerous sites where from 1 to 10 acres of water could be stored, which in heavy rains now runs unused off the land and out of the district.

The areas of least imbibition, then, are those where the unbroken marl is at the surface. The areas of greatest absorption of rainfall are those where the grit is exposed to the weather. There are other areas where the absorption of the rainfall is considerable but varies on the same spot in different years. These areas are the sides and bottoms of basins. It has already been mentioned that where the marl is thin the slight slope of a basin will show traces of gravel or some other form of the grit. Such an area is, however, to be considered as an exposure of the grit, but it will have a greater opportunity of absorption from the run-off of the slope of the marl above it. This, however, will be restricted by the fact that its pores are somewhat closed by the fine sediment brought down by the water from the marl slope. The bottom of a basin is, however, usually an area of considerable absorption of water. Since the settlement of the country these shallow lake-beds have rarely had water in them from one year to another. In most years they are simply a little moister than the neighboring prairie or ridges separating them. Whether the marl or the grit be the surrounding outcrop, the soil in the bottom of the basin is always somewhat different from that of the adjacent surface. It may hold alkaline contents; it is certain to contain argillaceous matter. In the drought of autumn and

the cold of winter these basin beds crack considerably. There are frequent cracks 20 to 30 feet long and sometimes 3 to 5 inches wide in parts and several feet in depth. When rain comes these cracks are the channels by which much water is immediately carried down out of the way of atmospheric evaporation.

SINK HOLES.

The extent to which water can be carried downward, and is actually so carried, is remarkably illustrated in Sherman County, Kansas, near the Colorado line, in section 23, township 8 south, range 42 west. The area referred to has been plowed several times and its basin form is not now conspicuous. It is rather part of a long slope inclining to the south, but the bottom of the old basin is still seen a little farther down

FIG. 58.—Sink hole in Sherman County, Kansas.

the slope. A part of the plowed area was left uncultivated in 1894, while the eastern part was planted with maize. At the end of May there were heavy rains and almost a cloud-burst at this point. A week later, while a man was cultivating the corn, one of his mules suddenly dropped into a large hole. It was found that there was a series of broad cracks, some over 2 feet across, running in every direction in the cornfield and in the adjacent old plowed land and extending over several acres. They stopped at the smooth sod, a square of which had been left around the site of an abandoned sod house. One of the broad cracks came up to a tubular well 95 feet deep at the east edge of the sod, and the tube, which had been 2 feet above the ground, sank to 2 feet below the surface.

When the cracks were discovered men went down some of the large fissures, from 6 to 8 feet deep, and under the parts where the cracks were

narrow, as in a tunnel. Earth has since fallen from the sides, and the depth is less conspicuous, but the cavities can still be seen extending many feet under the surface cracks, which seem like broken arches over longitudinal caves. The slopes to the Beaver south and east show outcrop of the grit, and here are large fissures in the soil which will carry down to the porous grit itself all the water falling on the area, and at the well the fissure reaches down to the permanent water level. The storm of last May probably only completed a process of widening natural channels that percolating waters had been busy performing for ages. With all its facilities for absorbing water and taking it through cracks and fissures, the surface of this whole region probably imbibes enough of the rainfall to allay all anxiety on the part of the settlers as to the constancy of the supply of the sheet waters of the plains.

RAINFALL.

The rainfall on the one hundred and second meridian possibly reaches an annual average of 18 inches. There are, however, no certain data in this matter. Records covering seven years, kept at Fort Wallace, gave an average in excess of 19 inches. Stations now are multiplied, but it will take several years to obtain trustworthy averages. The thing most certain is that the amount of precipitation is very irregular. At Fort Dodge, Kans., on the one hundredth meridian, the annual rainfall varied in fourteen years from under 11 to over 35 inches. At Imperial, Nebr., 1892 had 25.55 inches of rainfall; 1893 had 10.85; 1894, still less.

These seasonal irregularities and the occasional heavy rains favor a large imbibition in the absorptive areas and a large, rapid run-off in the areas where imbibition is slow. The rapid run-off, as has before been remarked, would supply considerable water to reservoirs constructed to conserve these storm waters.

The recent dry season has supplied evidence as to the local origin of the underground waters. In a well at Sharon Springs, Kans, the water surface was several feet lower than it was a year before, although the well contained an abundance of water. It is generally stated in the district that the fall rise of the forks of the Republican was delayed for a month in 1894. No regular measurements of the height of water in Frenchman Creek have been made, but it is probable that there was diminution as well as delay.

RATE OF PERCOLATION.

The rate of percolation of the underground waters is still unknown, little direct evidence being as yet available. In a report by Mr. E. S. Nettleton[1] an opinion is given, with some reserve, that 1 mile a year is not too great for the rate of movement of water in the loose alluvium of the Platte and Arkansas valleys, but that this rate is not reached in

[1] Senate Ex. Doc. No. 41, Fifty-second Congress, first session, Part II, pages 34–38.

the valley of the Rio Grande and at other localities. Mr. W. W. Follett[1] states that, judged from the amount of water pumped from a well at Garden City, Kans., the inflow must have a current of about 5 inches per minute through the gravel immediately adjacent to the perimeter of the well. He further states that the rate of flow has been found to vary all the way from one-eighth of an inch to 5 inches per minute, or, excluding the example just given, from one-eighth to 1 inch per minute, and he concludes that the rapidity of motion is not sufficient to cause a large body of water to pass a given point per day.

The present investigation contributes two facts, but their bearing is entirely confined to percolation in the alluvium of the South Platte Valley. They do not assist in computing the flow of the subwaters of the uplands. The freshet of South Platte River, to which reference has already been made, occurred on June 4, 1894. At that time E. E. Leech was scraping out a trench to reach the underflow of the valley, this trench being planned to be 200 feet long and 20 feet deep. About 30 feet of the length was finished at the time of the freshet. The trench is 10 feet deep and has 5 feet of water in it, which yields to a steam centrifugal pump a cubic foot per second. It is exactly half a mile from the river bed. In sixty hours after the flood came down the water in the trench was raised 1 inch. In twelve hours more it had risen 12 inches higher, and in eight hours later it had a total rise of 20 inches. Percolating through the comparatively dry sand, it moved, if we take half a mile as the distance (though it would probably be more, moving diagonally), at a rate of 129 feet per hour. After the sand was saturated the rate of motion was increased.

At Ogallala, Nebr., there is a ditch alongside the railway, between 1,000 and 1,200 feet from the river bed, with which, however, it has no surface connection. The water of the freshet came down in the night. Before sundown next day there was water standing in this ditch, the result of percolation through the sandy alluvium. In about twenty hours the distance from the river had been thus traversed at a rate of between 50 and 60 feet per hour. The whole Platte Valley responded to this subirrigation by bountiful crops of hay in the dry fall.

VOLUME OF THE UNDERGROUND WATERS.

It has already been remarked that the volume of water, whether in the form of underflow of the valleys or of sheet water of the plains, though great, has not been approximately estimated. Its depth is not known because very few wells ever go to the bottom of it. The owners and drillers of wells are usually satisfied when they get what they deem a sufficient supply. The depth of water in town or railway wells is usually greater than that in private wells. The former may in most

[1] Official Proceedings of the Third National Irrigation Congress, held at Denver, Colorado, September 3 to 8, 1894. The Underflow of the Great Plains, by W. W. Follett, pp. 34–38.

cases indicate the supply of the district, but, of course, not the whole supply.

The wells of the region may be classed mainly in two groups—valley wells and upland wells.[1]

VALLEY WELLS.

The valley wells are all shallow, usually less than 20 feet. There are very few of them whose depth to water is beyond the reach of an ordinary suction pump. But this depth varies not only in different valleys but in different parts of the same valley. Farther east some stream beds are cut deep into the alluvium of their bottom land, and therefore drain it much deeper than where the height of the banks is only 2 or 3 feet, and deeper wells are necessary. In the region inves-

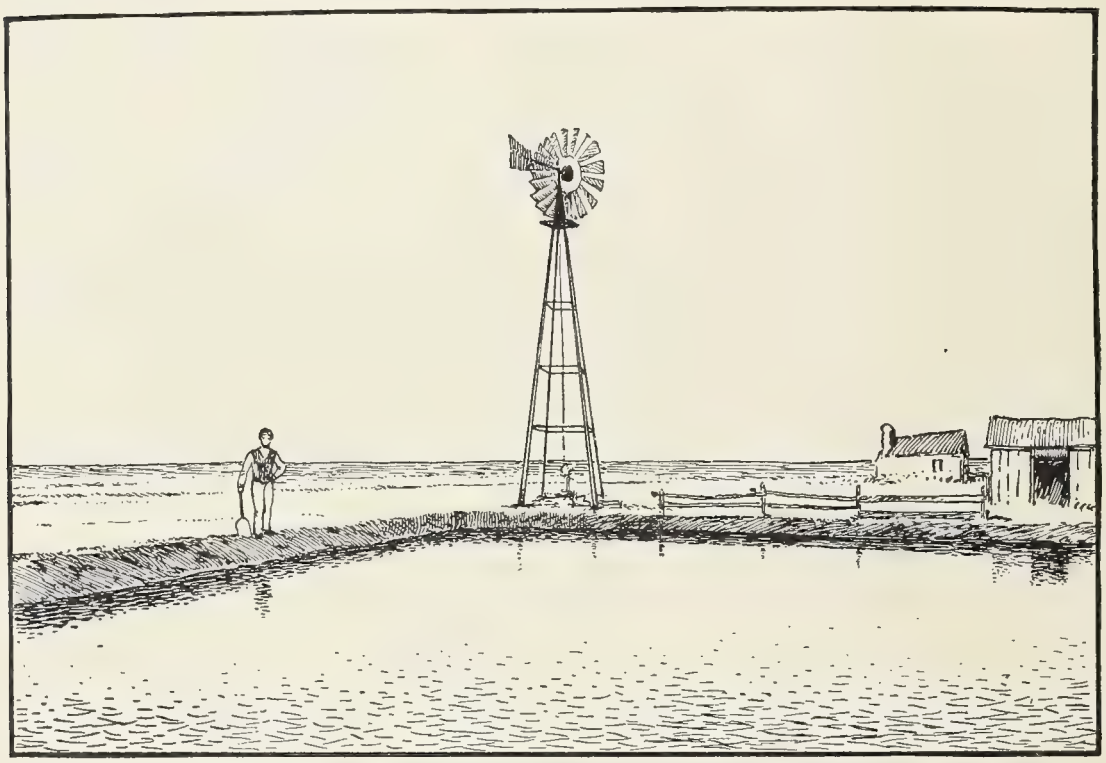


FIG. 59.—View of windmill and pond in Sherman County, Kansas.

tigated this deep cutting scarcely occurs, but some of the smaller valleys have made rather deep cuts. To the east, in the northern tier of counties in Kansas (as in Rawlins and Decatur), the drainage of the alluvium by the deep-cut stream beds, Sappa and Prairie Dog creeks, has been checked by the building of numerous earthen dams, which, holding the waters at a higher level, have restored the subirrigation of the bottom lands and made permanently productive many hundred acres in those valleys. This is a method of water use that is largely available in small valleys everywhere, especially where the shales or clays are present to make good foundation for the dams.

In the South Platte Valley the wells vary in depth: from 12 to 16 feet at Ogallala, 14 to 24 feet at Big Spring, 13 to 20 feet at Julesburg. The

[1] Detailed descriptions of wells examined are given in Bulletin of the United States Geological Survey No. 131, pp. 92-126.

same range is observable in the whole of the valley between the towns, the deeper wells being usually farthest from the river bed. At each of the three towns is a railway well. That at Big Spring is operated by a wind pump with a wheel 26 feet in diameter. The well is 14 feet deep, of which one-half is water. The pump will often lift 500 gallons per minute for a considerable length of time without changing the level of the water. It is believed that the seepage of the spring from which the town is named aids this well, and this is, therefore, an instance of the underflow of the valley being reenforced by the drainage of the sheet water of the uplands. The spring is 20 feet higher than the bottom land, and comes directly out of the grit. The other wells of the neighborhood have from 3 to 7 feet of water. The railway well at Ogallala is worked by a steam pump. It is 12 feet deep and contains ordinarily 7 feet of water. It is not worked continuously. Lifting 6,000 gallons per hour for six hours lowers its surface, which, however, regains its usual level very soon. The level varies also with that in the river bed, from which it is distant 60 or 70 rods. The well at Julesburg is 20 feet deep (14 feet in diameter), of which 5 feet are water. The steam pump will fill the 50,000-gallon tank in four hours; this lowers the surface of the water a little, but the amount is restored in a short time.

Some wells back from the river are from 20 to 30 feet deep, having from 3 to 8 feet of water. No wells in the Platte Valley are lowered by any windmill power. In valleys of the North Fork of the Republican and of the Arikaree, wells are from 18 to 30 feet deep, a few reaching the Cretaceous shales. Some wells in Haigler, Nebr., which seem to be in bottom land, are much deeper, being more than 60 feet under the Plains marl. They probably find their water in older débris of the grit. At Benkelman, Nebr., wells a little way back from the river are also deeper, over 70 feet, apparently all the depth being in packed sand. Probably the sand-hill region here encroached on the ancient valley. The Burlington and Missouri Railway has pumping stations at Benkelman and Haigler, Nebr., and at Wray, Colo. At each place there is a wind pump with a 20-foot wheel. There is an auxiliary steam pump at Benkelman. The depths and quantities supplied are as follows:

Place.	Depth.	Size of pump cylinder.	Daily use.
	Feet.	*Inches.*	*Gallons.*
Wray, Colo	14	4 by 12	30,000
Haigler, Nebr	34	4 by 12	25,000
Benkelman, Nebr	15	4 by 12	40,000

There are wells in both these valleys outside the towns, and they could be multiplied indefinitely, though the presence of shales on the slopes and in portions of the apparently bottom lands makes some deduction necessary from the statement that all the bottom lands

have the valley underflow beneath them. In part of the town of Haigler the boring of wells is useless, as the shales are reached without obtaining water. In various parts of the valleys the presence of the shales is indicated by the mineral qualities of the waters.

In the valley of the South Fork of the Republican the same conditions largely prevail. The shales outcrop on the south side, and the area of bottom lands is restricted. Still the water in the sandy alluvium is abundant. The railway well at St. Francis, drawn upon by a 20-foot windmill, supplies a daily consumption of 20,000 gallons, and other wells in the town have all they want, irrigating gardens and furnishing an abundance for all domestic uses. Other wells penetrating the shale at greater or less depths obtain no water. A well 6 miles down the river from Benkelman reached the shale at 29 feet and got a little water in its upper part.

It has been already remarked that the North Fork of the Smoky has but little bottom land, but there is water under it at a depth of a few feet, and this is true also of Goose Creek and the South Smoky. The last, however, has a wide, continuous bottom, and on the dry reaches of its bed in Colorado water is in the sand very near the top. This has been discovered by the coyotes, who in this dry year (1894) have scratched away the sand and gravel in numerous places to get the water. Some wells on low second bottom in Kansas, about 6 miles east of the State line, get water at 6 or 8 feet, and touch the shale 2 feet deeper. At Old Cheyenne Wells the depth to water is 13 to 15 feet. At Allman's well, southwest of Wallace, Kans. (well No. 113[1]), it is 10 feet. At both places there are from 2 to 5 feet of water in the wells. They do not reach the shale, which, however, is very near the surface in the more eastern locality.

The following table gives approximately the area of bottom lands in the region investigated—15 miles on each side of the one hundred and second meridian—in which water is obtained in large quantities at less depth than the limit of a common suction pump:

Valley lands having water within 25 feet of the surface.

Valley.	Estimated average width.	Length in district.	Area.
	Miles.	*Miles.*	*Sq. miles.*
North Platte	1.25	32	40.00
South Platte	1.50	32	48.00
Republican:			
North Fork	0.50	35	17.50
Arikaree	0.25	25	6.25
South Fork	0.50	40	20.00
North Fork of Smoky Hill	0.12	15	1.80
Lake Creek	0.12	10	1.30
Goose Creek	0.25	5	1.25
South Fork of Smoky Hill	0.50	30	15.00
Eagletail Creek	0.12	5	0.65
Others			10.00
Total area			161.75

[1] Bull. U. S. Geol. Survey No. 131, pp. 116, 126.

A strip of the same width west of the area examined would have a decrease of valley lands to the extent of 50 per cent. Eastward there is probably an increase in the same ratio. In the district the thickness of this water-bearing alluvium can not average less than 5 feet. In the Platte valleys it is much more. Probably exception will be taken to the width given to the North Platte Valley as being too narrow. It may be said in regard to this that the north side of the valley was not examined, and on the south side much that looks like second bottom is in fact Tertiary grit. For reasons already given it must be understood that the estimates for the Republican forks are only approximate.

UPLAND WELLS.

A cursory examination of the well records and of the maps and diagrams accompanying this report will show that all the wells not in the valleys or in some ravine are deep wells. As has already been stated, the depth of the wells varies for each plateau according to the geological and topographical structure. The profile of the country from north of Burlington, Colo., to north of Goodland, Kans. (Pl. XLII, fig. 4.), shows that the water level lowers eastward with the general decrease of altitude, and is modified by local variations of the elevation. Fig. 3, Pl. XLII, which is a similar profile at right angles to fig. 4, shows more irregularity of the water table, which is undoubtedly owing to the variable structure of the water-bearing grit. The slope of the water table to the east is probably due to the fact that the Cretaceous shales under the grit have about this slope. If the section were extended an equal distance westward, the shales would be shown nearer the surface; if eastward, they would be found coming up in Thomas or Sherman counties, Kansas, where, however, the water supply is abundant.

DEEP WELLS.

In the plateaus north of the Frenchman the shales are not visible. The controlling factors there as to the depth of the wells are the depths of two draining valleys (the two Plattes) and the thickness of the Plains marl. The thickness of the marl counts for something on every plateau where it exists at all. The deepest valley is that of the North Platte, and along the top of the bluffs on its south side the Plains marl is the thickest also. Therefore the wells near that line of bluffs are the deepest found in this investigation, being from 300 to 430 feet deep. A few of those wells are not copious in their supply, but this is doubtless attributable to lack of skill or care in drilling, tools having been lost or jammed, or sand not shut out. Some of the wells on this plateau passed through a small supply of water at a depth of less than 100 feet, but this is probably drained out mostly by the ravines in the gravel hills, which come far into the plateau.

The plateaus south of the South Platte repeat the phenomena of the one to the north, but the wells are not quite so deep, because the Plains marl is thinner and the drainage is less deep. Still, the wells on the north edge of the divide—at Grant, Venango, and at other places farther west—are from 170 to 200 feet deep. Toward the south they decrease in depth, and in the sand hills some are decidedly shallow. On the divide between the North Fork of the Republican and the Arikaree, and again south of the Arikaree, the wells increase in depth with the thickness of the Plains marl. Near Lansing this is 35 feet thick. At Idalia it is 68 feet; and 4 miles north of Idalia, at the edge of the descent to the Arikaree, it is 100 feet. Other factors come in, as the wells are not as much deeper as the marl is thicker. Probably the surface of the

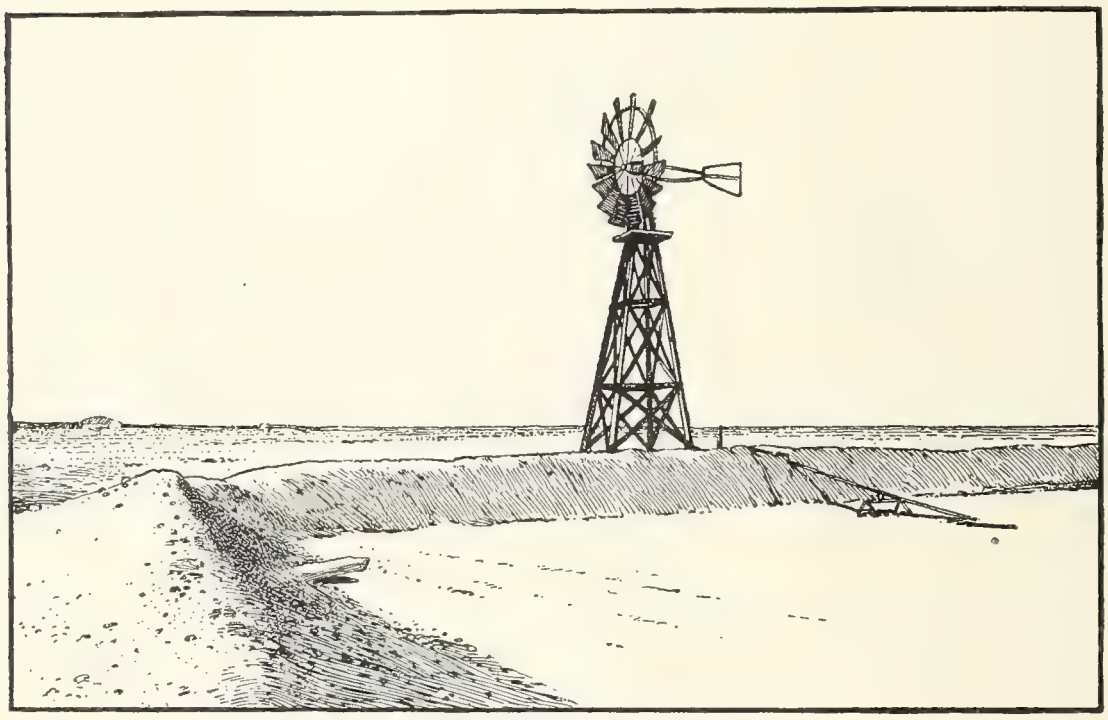


FIG. 60.—View of windmill and empty reservoir.

shales below is the one important factor, reducing the thickness of the grit by its elevation. The shales outcrop at varying heights in ravines of the Arikaree. The wells on this plateau have from 4 to 12 feet of water. In Colorado they are 200 feet to 230 feet deep; in Kansas, from 170 to 200 feet. On the plateau north of the Arikaree the wells south of Laird are 80 to 90 feet deep (Well No. 72, Bull. 131, pp. 107, 114), 2 miles west they are 100 feet deep, and 7 miles farther, 190 feet. Thence they decrease in depth. No. 72 has abundance of water. The plateau in Kansas east of St. Francis seems to continue eastward the conditions of the Idalia-Gurney table of the west. (See Pl. XLII, figs. 2 and 3.) The wells near Wheeler are over 200 feet deep, and the marl has a thickness of 40 to 60 feet. They are about the same depth at Lawnridge. All have from 10 to 20 feet of water. The wells between

the two Smoky forks are not so deep, but increase in depth westward, and south of the South Smoky the increase from 160 feet at Weskan to 265 feet at Cheyenne Wells is very marked. The railway well at Weskan (Well No. 116, Bull. 131, pp. 116, 126), on slightly lower ground than the others, is 143 feet deep, with 7 feet of water, and is lowered some by the steam pumps used. There is also a railway well at Cheyenne Wells which is 257 feet deep, with 25 feet of water.[1] Within a few rods, at the same surface level, is a city well, also with a steam pump. The depth is 265 feet, and there is 18 feet of water. A well 2 miles to the northwest (Well No. 16, Bull. 131, pp. 106, 109), had a depth of 181 feet, with 4 feet of water. The marl in this region is from 20 to 60 feet thick, thinning to the edge of every draw. The other railway wells of the high prairie are at Goodland, Kanorado, Holyoke, Grant, and Imperial. At Goodland the depth is 176 feet, with 19 feet of water, and it is practically the same at the city wells half a mile north, which are also worked by steam pumps. The water in the railway well rises 5 feet after a rest, which the pumps reduce again, but can not lower below that level. Another well in the city has 40 feet of water. The railway well at Kanorado is 140 feet deep, with 40 feet of water. There is a steam pump, which fills the 1,600-barrel tank without lowering the water, and there has been no indication that it interferes with other wells near, which, 20 feet less in depth, have 20 feet of water. The railway well has ceased to be used at Burlington, but the town well there has abundance of water. On the Frenchman-Platte plateau there are numerous wells, and the three railway wells at Imperial, Grant,

[1] Union Pacific Railway well at Cheyenne Wells, Cheyenne County, Colo.; completed in 1882; diameter, 10 inches; bored; total depth, 257 feet; depth of water, 25 feet; water rose slightly when struck; depth of water does not vary, except that it seems there is a little more water when wind is from the northwest; water obtained from the well fills 50,000-gallon tank in forty-eight hours; can not be easily lowered; water raised by steam pump and used for a railway division station; some gas still comes from the old Government boring with which this well was connected.

Prof. Orestes St. John, in an article on artesian wells in the fourth biennial report of the Kansas State board of agriculture, has preserved the record of the Government test boring made in 1882, as here appended:

Section of the artesian boring at Cheyenne Wells.

		Feet.
Plains marl	1. Surface clays	30
Tertiary grit	2. Chalky rock	30
	3. Gravelly clay	50
	4. White, sandy clay	20
	5. Soft, white sand	15
	6. White, sandy clay	40
	7. Soft sand, alternating with clay	80
	8. Soft, white clay	20
Laramie (?)	9. Soft, black shale	319
Montana group	10. Soft, white, arenaceous shales, with gas veins at 610 and 640 feet	726
	11. Chalk rock; slight inflow of brackish water near base	70
	12. Fine sand	30
	13. Soft, black shale	100
Colorado group	14. Soft, white, calcareous (?) rock	50
	15. Black shale	190
	Total	1,770

The names in the first column indicate the opinion of the present writer (Hay) as to the geological age of the strata indicated.

and Holyoke are conspicuous. Their supply of water will be best seen for purposes of comparison in tabular form, as follows:

Railway wells on the high prairie (Burlington and Missouri Railroad).

Place.	Total depth.	Depth of water.	Daily use.
	Feet.	*Feet.*	*Gallons.*
Grant, Nebr	200	40	36,000
Imperial, Nebr	137	18	30,000
Holyoke, Colo	175	40	30,000
Akron, Colo	100	38	18,000

Akron, which is beyond the limits of the field of this investigation, being well upon the prairie west of the sources of the Republican, has also a town well yielding 12,000 gallons a day. The railway well has a wind pump with a 20-foot wheel. The other stations in the table use steam pumps. That at Grant reduces the water to exhaustion, but it is restored again speedily. The well at Grant, and one at Venango, 190 feet deep with 40 feet of water, as compared with Imperial and with Lamar, whose town well is 90 feet deep with 30 feet of water, illustrate the greater depth near the northern edge of the plateau, and the depth at Holyoke illustrates the westerly increase. These facts are further illustrated in profiles (Pl. XLII, figs. 5 and 6) taken from Mr. Follett's report[1] of 1891, which show by the statement of strata passed through that the grit formations come to the surface in all this region, which has been described here as one where the proportion of rainfall imbibed must on this account be very large.

In the region east of Imperial, a town beyond the reach of the present inquiry, the wells are deeper, going over 300 feet. I have not been able to see this region personally, but it is probable that there is a covering of the Plains marl of considerable thickness, and that the deep-cut channels of the lower part of the Frenchman and of Spring Creek lower the water in the Tertiary grit under the high prairie. The high level of the North Fork of the Republican west of Wray suggests a sufficient reason for the comparatively shallow wells at Akron.

The strip of country between the Frenchman and the sand hills to the south has wells of much less depth than the plateau to the north. Well No. 1 (Bull. 131, pp. 95, 97), 6 miles southwest of Champion, Nebr., has 6 feet of water in depth of 64 feet, and Well No. 27 (Bull. 131, pp. 95, 99) is 39 feet deep, with 9 feet of water. It is 6 miles south of Lamar, Nebr., at the edge of the sand hills. Wells in the Frenchman Valley from Champion west are only from 15 to 30 feet deep. They are not in alluvium, but in the grit, which has a soil covering of from 3 to 5 feet.

Wells in the sand-hill region are variable in depth, and the number of them is not so great as to make the generalizations very certain, but it would seem that the depths are least in the central region, and that

[1] Senate Ex. Doc. No. 41, Fifty-second Congress, first session, Part II, pp. 22-23.

there is increase westward. Two in Colorado are 80 and 100 feet, while others in both States vary from 18 to 60 feet. (See Wells No. 74, Bull. 131, pp. 107, 114; No. 28, Bull. 131, pp. 95, 99; No. 5, Bull. 131, pp. 95, 97; and No. 71, Bull 131, pp. 96, 103.) They all reach the so-called "magnesia" or other form of grit without intervention of the Plains marl between it and the surface sand. Wells deepen outside the sand hills eastward.

WATERLESS WELLS.

Where the Cretaceous shales crop out in the bounding valleys the wells are not so deep as they would otherwise be on the plateaus, and in some cases the shales have been denuded of such water-bearing formations as once covered them, and no water is found. This occurs on some benches of the Republican forks, and also in the highlands between the head of the Hackberry and the Arikaree. Well No. 23 (Bull. 131, pp. 114, 118) is 175 feet deep. It is 135 feet in the plains marl and 40 feet in the shale, but there is no water. A well on SW. $\frac{1}{4}$ sec. 30, T. 1 S., R. 41 W., repeats the same phenomenon, and others in the same district and also west of Idalia have small or no supply of water from the same causes.

The largest area now known in which the water-bearing grit is absent where general appearances would warrant the expectation of finding it is at Sharon Springs. Two miles to the north the Smoky bottom has water in the alluvium, and within the townsite on its south side the Eagletail Valley has also abundance, but in the town itself and the hill rising to the north wells have found only a little poor water on top of the shale under 20 to 50 feet of the Plains marl. There is a thin sheet of gravel or other débris where the little water is, and this outcrops on some of the slopes, which shows the former presence of the grit before the mid-Neocene erosion, but for several miles north of the Smoky (and on some of the slopes of Goose Creek to the northwest) the grit is present only in small quantities, and Lake Creek is crossed before the wells have the normal plains abundance of water. All the smaller valleys and arroyos, however, have sandy and gravelly alluvium and supply wells at small depths.

ARTESIAN FLOW.

It has been previously remarked that over 300 wells have been examined in this investigation. Of about 100 of them the drill records, however imperfect, have been studied. Only 40 show that the water rose above its level when the drill pierced it. In only 1 did it flow over the surface, and that was a temporary phenomenon, which, however, occurred three times within a year. In only 2 others did water rise as much as 100 feet, and one of these is a deep well on the plateau of Deuel County, Nebraska, where there is also another in which the water rose 95 feet. The other 100-foot rise is in Cheyenne County, Kansas. In 24 others the rise was from 26 feet down to 1 foot. In 12

the rise is simply said to be "a little." The following table includes all wells showing artesian flow:

List of wells in which water rose above the level where first reached.

No.	County and State.	Location of well.			Depth at which water was reached.	Height of rise.	Described in Bulletin 131.
		Section.	Township.	Range.			
					Feet.		*Page.*
7	Chase, Nebr	4	6 N.	38	92	A little	95, 97
9	do	4	6 N.	38	87	A few feet	95, 97
13	do	10	6 N.	39	90	do	95, 98
3	do	23	6 N.	39	21	1 foot	95, 96
16	do	16	7 N.	41	60	do	95, 98
48	Colorado	17	7 N.	42	110	25 feet	107, 112
100	Perkins, Nebr	7	9 N.	41	150	A little	96, 105
101	do	34	9 N.	41	137	15 feet	96, 105
96	do	13	10 N.	39	160	A little	96, 105
97	do	9	9 N.	38	114	(*a*)	96, 105
98	Keith, Nebr	6	13 N.	38	5	A little	96, 105
44	Deuel, Nebr	14	13 N.	42	150	do	95, 100
43	do	24	13 N.	43	119	4 feet	95, 100
51	do	12	13 N.	44	212	13 feet	95, 101
42	do	18	13 N.	42	277	127 feet	95, 100
41	do	20	14 N.	42	217	Slightly	95, 100
39	do	32	14 N.	42	226	9 feet	93, 100
49	do	24	14 N.	42	268	18 feet	95, 101
48	do	13	14 N.	42	325	95 feet	95, 101
75	Keith, Nebr	22	13 N.	41	15, 17	2 feet (*b*)	96, 103
53	Sedgwick, Colo	4	11 N.	44	27	A little	107, 112
63	do	12	11 N.	45	40	A few feet	107, 113
50	do	18	12 N.	42	12	A little (*c*)	95, 101
21	Chase, Nebr	35	8 N.	41	61	1 foot	95, 98
23	do	29	7 N.	41	67	14 feet	95, 98
5	do	8	5 N.	41	32	16 feet (*d*)	95, 97
72	Dundy, Nebr	7	4 N.	41	16	1 foot	96, 103
62	do	5	3 N.	41	14½	do	96, 102
74	Colorado	4	3 N.	42	70–80	10 feet (*e*)	107, 114
33	Cheyenne, Kans	6	3 S.	40	126	1½ feet (*b*)	115, 119
39	do	9	4 S.	39	214	100 feet (*b*)	115, 119
8	Arapahoe, Colo	35	3 S.	43	221	1 foot	106, 108
19	Cheyenne, Kans	4	4 S.	40	65	5 feet	114, 117
87	Sherman, Kans	22	8 S.	41	110	26 feet (*f*)	115, 123
57	do	2	7 S.	41	130	A little	115, 121
55	Wallace, Kans	12	14 S.	40	129	6 feet	116, 125
106	do	27	13 S.	40	20	A little	116, 125
105	do	24	13 S.	41	50	5 feet	116, 125
103	do	34	13 S.	40	14	4 feet	116, 125
19	Cheyenne, Colo	21	14 S.	44	257	A little	106, 109

(*a*) In 1887 flowed for four hours about 10 barrels of water; a month later the same, and again six months later.
(*b*) The lower sheet rose to the upper.
(*c*) Varies 2 or 3 feet as river, which is three-fourths mile distant.
(*d*) Greenish "magnesia" above the water, two veins, lower vein rose to upper. In the sand hills.
(*e*) Eight layers of water, the lowest rising to the highest.
(*f*) This is at Ruleton. The water was pierced 4 feet, so there is 30 feet of water in well.

It will be observed in looking over the table that the wells are in all parts of the district, both in valley lands and on the high prairie. Many of them simply show the water rising to the height of another sheet of water above it, indicating the irregular distribution of the impervious beds (clays or marl) among the water-bearing strata. There is nothing in all these to encourage the expectation of flowing wells in this region, and yet, as in Meade County, Kansas, far removed from this district, there might be a limited area where the grit would be covered by impervious clays and the slope sufficient to carry the water down to a much lower level than at its outcrop, and so allow it to rise to the surface when tapped by the drill. This is a possibility. Owing to the great number of wells already put down in all parts of the plains,

it can not be said that it is a probability. The well of temporary flow (No. 97) southeast of Grant, in Nebraska, may possibly be connected with the phenomenon of blowing wells, to which reference will be made further on.

That deeper strata of the Dakota sandstones should yield water with pressure sufficient to raise it to the surface in this region is unlikely; first, because in the Arkansas Valley, where these sandstones yield artesian flow near the Colorado-Kansas boundary, the pressure is so little as to forbid the supposition that the source of it is more than a few score miles away; again, the slight flow from the same beds at Oberlin, in longitude about 100° 30′, is not more than can be produced by the small quantity of gas that comes with it. Again, the borings made down to these strata in 1882 at Akron and Cheyenne Wells failed to give evidence of artesian flow.

It would appear, then, though these beds are upturned on the flank of the mountains, either that they do not absorb much moisture there or that beneath the surface there is a breach of the continuity of the conditions necessary to the conveyance of the water with pressure enough to bring it to the surface in this region.

Though the evidence so far obtained in this investigation is unfavorable to the expectation of artesian flow of water, yet there would seem to be some reason why this matter should be decided finally by experiment. Three or four borings along the line of the one hundred and second meridian between the North Platte and the Canadian River would, if properly located and conducted, settle the question of artesian supply in an area of 100,000 square miles. The cost of this work probably need not exceed $25,000.

BLOWING WELLS.

This is a term used on the plains for wells which under certain circumstances give out currents of air and thereby make some kind of whistling or moaning noise, varying with the size and form of the aperture. Many of them previously noted[1] are in the region of this investigation. These are nearly all on the plateau between the South Platte and the Frenchman. Among them is the St. Elmo well, at Grant, the county seat of Chase County; others are near Holyoke. It is said that the outblow and noise always precedes a windstorm. I was on this plateau in such a storm, and was told that before it commenced these wells had been blowing hard. The inverse phenomenon, or intake of air, was in course after the storm when I saw the St. Elmo well. Light substances, such as feathers and paper, were drawn by a strong draft inward through crevices in the wooden covering of the well. It is said that the phenomenon is most noticeable when the wind is from the northwest. As this is the usual direction of storm winds in that region this fact does not militate against the explanation that the wells connect with cavi-

[1] Senate Ex. Doc. No. 41, first session Fifty-first Congress.

ties in the porous rocks, which hold such an amount of air that it responds, as does the air in mines and caves, to the varying pressure of the outside air, being aided by differences of temperature within the wells. The engineers at Cheyenne Wells believe that the supply of water is freer when the wind is from the northwest, and others make the same remark. This would indicate that the wells are simply barometers showing varying pressure of the atmosphere, and it may be that this was the cause of the three blowings of well No. 97, in Perkins County, Nebraska. There are no records in that case, however, and this is only a supposition. Such change in barometrical pressure, combined with possible changes in underground water currents, would suffice to produce the phenomena observed. At Winona, in Logan County, Kansas, is a well of this kind belonging to Mr. R. L. Smith, which was carefully compared with a mercurial barometer by Prof. J. T. Willard, of the Kansas State Agricultural College, and the barometrical character of the phenomena was fully established.[1] That temperature is a factor is certain, as variation of atmospheric pressure depends ultimately on variation of temperature.

TEMPERATURE OF WATER IN WELLS.

The conditions at most of the wells at the time of my visits were not favorable to observations on the temperature of the water, and a record could therefore be made of only fifteen. These had a range from 52° to 57° F., the average being 55°. Nine of the observations were taken on the South Platte-Frenchman table-land, and may afford an average of the temperature of wells there, which is 54.5° F. A single observation on the North Platte-South Platte table gave 54°. One in northern Cheyenne County, Kans., gave 57°. Three observations in the Smoky-Beaver region were, respectively: Kanorado, 56°; south of Presley, 54°; Old Cheyenne Wells (Colo.), 57°. Two of the high-level springs south of the South Platte have temperatures of 52° and 56°, respectively. Phelps well, at Big Spring, and the spring itself were both 56°. It is probable that all these temperatures are higher than that of the water in the underground strata. On this point the observations in Gibello Cave, southwest of Julesburg, are most reliable. The water in the fine conglomerate there was at 48° F., and the air of the cave 54°. It may perhaps be inferred from the observations made that the wells on the same table-land have about the same temperature, and that the wells of different plateaus or of the valleys do not differ widely from one another. No regular increase of heat based on the greater depth of wells has been observed, but the uniformity of temperature may perhaps indicate continuity of the water sheet. On account of the comparative coldness of the well waters it is usual to expose these in shallow reservoirs, that they may be warmed by the sun before being applied to the growing crops.

[1] See Transactions of Kansas Academy of Science, Vol. XIII, p. 73.

GEOLOGY OF THE DISTRICT.

In the preceding pages the water supply of the region has been discussed, with occasional reference to the geological structure of the country. In order that some of the conclusions there stated may be more fully understood, it is desirable to discuss at some length the principal geologic features and their relation to the topography. In its general aspect the geology of this region is simple, but in detail some of the relations are intricate. Certain formations presumably underlying the district are nowhere visible at or near the surface within its limits. The presumption of their presence is based on the fact that these strata are upturned on the eastern flank of the Rocky Mountains, to the west, and that they outcrop to the east of the area under discussion, in Kansas and in Nebraska. These are the Colorado and Dakota groups, of Middle and Lower Cretaceous age. Below these may also be expected, for the same reasons, the rocks of the Carboniferous period, and between these and the above-named Cretaceous, some still lower Cretaceous and the Jurassic, Triassic, and Permian may possibly have place, but to the east the evidence of this is wanting, though some of them outcrop in southern Kansas and in the Territory of Oklahoma, and some of them are seen on the flanks of the mountains.

FORMATIONS OCCURRING IN THE DISTRICT.

On parts of the plains near the mountains some higher Cretaceous rocks—the Montana group—are found, and above them lies the formation known as the Laramie, which may be regarded in some sense as transitional to still higher formations, classed as of Tertiary age. Some of the Montana beds—the Fort Pierre shales—crop out in the region of this investigation, and their presence has a distinct bearing on its economic problems.

The Tertiary beds of the plains with which we are concerned are of two kinds. It may be said generally that they do not reach the mountains. They are cut off from such contact by the deep valleys which run north and south to the east of the foothills. It is an interesting fact that in and to the west of these valleys there are traces of these Tertiary beds which show former extension, and one instance where a narrow ridge crosses the upturned strata of the foothills and overlaps on the granite, which indicates that the Tertiary lakes extended into the mountain valleys. They are now cut off, with this single exception, from even the appearance of contact.

Of the two formations of Tertiary age mentioned, one possibly belongs partly to post-Tertiary time. They are of considerable thickness in the district under investigation, and are of much importance in connection with the economic problem specially under consideration. It is in the older of these two formations that the principal intricacy referred to on a previous page occurs. The difficulty is, however, one

that affects the economic question only partially, and therefore will be referred to only so far as it does affect it. The entire group to which reference is made contains strata that are known to paleontologists as the White River beds, the Loup Fork beds, and the Equus beds, the last being the newest. Whether these all belong to the Middle Tertiary (Miocene), or to the latest Tertiary (Pliocene), or are divided between them, or are partly of post-Tertiary age, are questions on which paleontologists yet differ. That all of the parts given above exist in the district is also a matter of doubt. These beds, however, have certain physical characteristics, to be described further on, which have suggested a name that I have applied to their exposures in various parts of the plains, from northwestern Nebraska to Texas, in connection with the question of the water supply. For a large part of their thickness they have so much lime intermingled with arenaceous matter that they resemble chunks of old mortar, and the term "mortar-beds" has been applied to them; and gravel and sand being prominent in other parts of the section, the term Tertiary grit has been adopted and will be here used to include the whole series.

The other formation yet to be noticed I have called the Plains marl. It is, as this name indicates, composed of lime, sand, and clay. Its structure varies as one or the other of these ingredients predominates, but the lime is the one that is always less than the others. Sometimes sand is so much in excess that there is only enough of the other slightly to cement the arenaceous base. It is a surface deposit on the high prairie, but it is sometimes found forming the bottom land of the valleys, and it occurs in patches on the slopes. Its thickness varies from a few feet to two hundred. I regard it as of late Tertiary (Pliocene) age as to its inception, and probably its latest deposits were laid down in Quaternary time. Where it is thickest its lower parts are often more arenaceous than the upper.

Newer than the above is the alluvium of the various valleys. Mostly arenaceous, but with some argillaceous beds, it forms the bottom and sometimes the second bottom of the river and creek valleys and the beds of the streams themselves.

The following table exhibits in descending order the names of the formations as given above and as they will be referred to in the succeeding pages, with some subdivisions which it is not needful to describe, but which will sometimes be referred to:

Cenozoic	Quaternary		Alluvium.
	Tertiary	Neocene	Plains marl (Pliocene).
			Tertiary grit (Miocene).
		Eocene (missing.)	
Mesozoic	Cretaceous		Laramie (missing).
			Montana group, Fox Hills (missing).
			Montana group, Fort Pierre.
			Colorado group, Niobrara.
			Colorado group, Fort Benton.
			Dakota group.

DIP OF THE STRATA.

The general direction of the dip of the Tertiary beds is from north of west to south of east, and the subjacent Cretaceous beds have a similar inclination, modified by local synclines and anticlines.

There appears to have been a cessation of deposition at the end of the Colorado epoch, and some erosion of the surface, on which the Fort Pierre beds were afterward laid down, even as the older Dakota strata rest in the eroded hollows of still more ancient formations. But the mountain uplift at the end of Laramie time raised the body of the region we now call the plains out of its marine conditions and subjected it to long-continued erosion by the agencies of the weather in a climate whose temperature was higher than at present. In the region of which we are specially treating this erosion lasted probably through the whole of Eocene time.

PRE-NEOCENE EROSION.

This erosion cut out and wore away immense bodies of the Cretaceous formations. The farther east the more they are worn away and the deeper the valleys in them. In the region investigated whatever there was of the Laramie or Fox Hills was entirely taken away and the valleys were cut into the Fort Pierre formations. Farther east the corrasion cut down into the Colorado group. At the close of this period of erosion the surface of the land was rough, as it is now, with deep canyons in the Cretaceous shales.

The circumstances that led to the succeeding overflow of fresh water and the extensive lakes with few Cretaceous islands above their surface are not discussed here. The previous rise and whatever of subsidence now took place were so gentle that there are very few marks of flexure or fracture in the Cretaceous beds of the plains. The waters were charged with lime, and all the beds we have included in the term Tertiary grit were deposited. The depression was greatest toward the north, as the beds are there the thickest: at the White River of Nebraska, over 1,000 feet; at the Red River of Texas, about 100 feet. The depression becomes more sudden north of the Republican River. There we see the Fort Pierre shales with considerable thickness of outcrop. The Cretaceous rocks do not show again south of the White River. The Tertiary grit filled all the valleys and covered most of the intervening spaces of the Cretaceous surface, leaving here and there a few islands which, strange to say, have an important relation to this economic investigation. When these early Neocene (as I believe, Miocene) deposits were completed and the relation in height of land and water was changed, the drainage began again nearly on the old lines, and we have the period of mid-Neocene erosion.

MID-NEOCENE EROSION.

The valleys were cut out in a great part of the plains region through the Tertiary deposits and into the subjacent Cretaceous beds—in the region of this special work into the Fort Pierre shales. In the northern part, however—that is, in the two Platte valleys—the bottom of the Tertiaries was not reached before there was another change, and the region was again covered with water, which deposited over all the plains a bed of marl varying in thickness from 1 foot to 200 feet. It is not easy to determine whence came the calcareous parts of the Tertiary grit, but the origin of the marl seems to have been in the wearing away by water of the beds of the grit, particularly of the more uniform White River beds of the north and northwest. Deposits found in little hollows where the débris of these beds is carried by rain storms are identical in structure with the vast body of the Plains marl. At the end, or in the last phases of the Plains marl, the lakes or inland sea began to be drained again, largely on the old lines, and we have the post-Neocene erosion.

POST-NEOCENE EROSION.

This has lasted to the present day. Many valleys have been cut down through marl and grit to the subjacent Cretaceous rocks, and these rocks have in places been cut to a lower level, while some valleys of the older erosions are permanently closed and some entirely new ones have been formed. The flood plains of the valleys have alluvium 20 feet thick, and in a few places thicker than that.

A statement of the order and extent of these successive erosions may now be briefly made, though the obtainment of the facts upon which it is based required long and wide observation. The generalization is simply a deduction from the observed conditions. In one place the Plains marl is found resting on the highest beds of the Tertiary grit. A short distance away, lower down a ravine, it is found resting on a lower bed of the grit, the surface of which is very uneven. Such conditions are to be seen in every valley of the district from the North Platte to the Smoky. In the valleys of the Republican forks the Fort Pierre shales are found outcropping with the grit resting on their uneven surface, and in the same valleys the marl may be seen descending through breaks in the grit and resting on the shales. This is repeated also in the valleys to the south. In wells near the head of Hackberry Creek, south of the North Fork of the Republican in Kansas, and on the divide between the Arikaree and the South Fork in Arapahoe County, Colo., the shales are reached under the marl without the intervention of any form of the grit. These wells are without water. The same conditions are shown, as before stated, by wells at and near Sharon Springs, in Kansas. Diagrams show this better than words, and the reader is referred to those that accompany this paper.

SOUTHEASTERN LIMIT OF FORT PIERRE BEDS.

The southeastern limit of the Fort Pierre shales is a line extending from a point in the Republican Valley below Republican City, Nebr., southwestward across Phillips and Norton counties, Kans., to the middle of Logan County (where they show south of Winona and in the valleys of the Smoky, farther west), and across into the valley of the Whitewoman in Greeley County. They therefore may be considered as underlying the entire region of this inquiry, though not showing everywhere. They are mostly clay-shales impregnated with alum, gypsum, calcite, and other minerals, but there are in places beds that are highly carbonaceous, with thin laminæ, and these are to a certain extent combustible. The relation of these shales to the water supply is very important, as will appear later.

RESULT OF GEOLOGIC STRUCTURE ON TOPOGRAPHY.

The topography of the district is confined to the three geologic formations most fully described above, viz, the Plains marl, the Tertiary grit, and the Fort Pierre shales. In one important respect the marl and the shales have a similar topographic aspect. Where they appear over any considerable extent of surface they both have a general smoothness of contour. The shales are, however, the rougher of the two. When seen in section in steep bluffs the grit is still more rugged, and the shales have ruggedness in the same situations. This is owing to the fact that nearly everywhere the shales have hard, concretionary masses that stand out and protect the softer parts, and elsewhere they have a vertical fracture that gives them steep fronts.

TOPOGRAPHY OF THE MARL.

The marl is the most extensive surface covering in the selected district. The general appearance of by far the greater part of the region is due to it. Passengers on the Rock Island Railway west from Colby, Kans., to Burlington, Colo., and on the Union Pacific Railway in Wallace and Kit Carson counties, see its general smoothness, with the sod of buffalo and grama grass. It is the subsoil of the plains, and is fertile to the bottom. It is gently rolling, and the basins formed in it are conspicuous features of its surface everywhere. In my field notebook I have this entry, or equivalent words, in many places: "The whole country is a series of gentle swells separating large inclosed basins. Some of the larger basins include several smaller ones." These statements are applicable in whole or in part to every interfluvial plateau of the region. The precipices of the marl present a bold and highly characteristic appearance in the exposed sections, in canyons, and most effectively at the head of ravines where a deep canyon cuts through the marl and to, and sometimes into, the subjacent rocks. The fronts are deeply niched and the buttresses take a rounded or conical form.

The surfaces of such bluffs are mostly of a creamy-yellow color, sometimes looking white from being covered with an almost impalpable powder which the wind blows away. This shows itself in the side walls of cellars and wells on the level prairies, and the subsoil is sometimes spoken of as white soil or flour soil. It is also called canyon clay, and yellow earth. The yellowness is rarely darker than a rich cream color. The lime in the marl is sometimes found as irregular concretions resembling the loess-kindchen of regions farther east. Indeed the marl has been called loess by geologists of both Nebraska and Colorado, and it has been already said above that its formation may have been in part contemporaneous with that of the loess. Like the loess, also, the marl often forms the second bottom, and sometimes the only bottom, in river valleys, its smooth surface and bench fronts rendering it scarcely distinguishable from the more compact alluvium.

It is in the marl that the great northwest-to-southeast grooves are cut, mentioned on a previous page; and it may be remarked that those on the north of the South Platte suggest by their general appearance that they were the beds of the North Platte at earlier stages of its existence; and some of the others are in line with valleys on the opposite side of the rivers to which they are tributary, suggesting larger

FIG. 61.—Ideal section illustrating the thinning of the Plains marl.

volumes of water, with a greater incline, rushing across the space where the main valley now is.

In almost all the region the southern slope of the interfluvial plains is caused by a thinning off of the marl. This is illustrated by the depth of wells on the northern part of the divides. The marl itself does not contain the water that supplies the wells, but it has to be penetrated to reach the water-bearing strata. The following generalized diagram applies to land between the Plattes, between the Republican forks, and between the Beaver and Smoky Hill forks. The topographic features of the marl may be summarized thus:

The horizontal surface is smooth and covered with buffalo and grama grasses.

There are numerous shallow basins, often in lines, the lines sometimes suggesting grooves.

The vertical exposures in bluffs and canyons have a rounded or semiconical appearance.

TOPOGRAPHY OF THE TERTIARY GRIT.

The grit in all its exposures has a very pronounced topography, and its forms are diverse because of the varying character of its beds. In the valley of the North Platte its variations are quite distinct. The

highest beds of the outcrop there are white, soft, limy grit, lime preponderating, so that where a surface is nearly horizontal it approaches smoothness. The weathered surface is hard and in detail rough, and this roughness is indicated by the grasses which take possession of its harder surface—blue stem and some bunch grasses. Lower down the Platte slope the conglomerate is weathered out and there are areas of conical hummocks and oblong mounds with gravel on top and sides. In the vertical faces the blocks of conglomerate are of all sizes and are tumbled at all angles; some are cuboidal, some large slabs. The hummocky areas are very remarkable in this aspect from above, but they are not so difficult to cross as the canyon region of the marl or the softer beds of the so-called "magnesia" of the grit. The beds of the

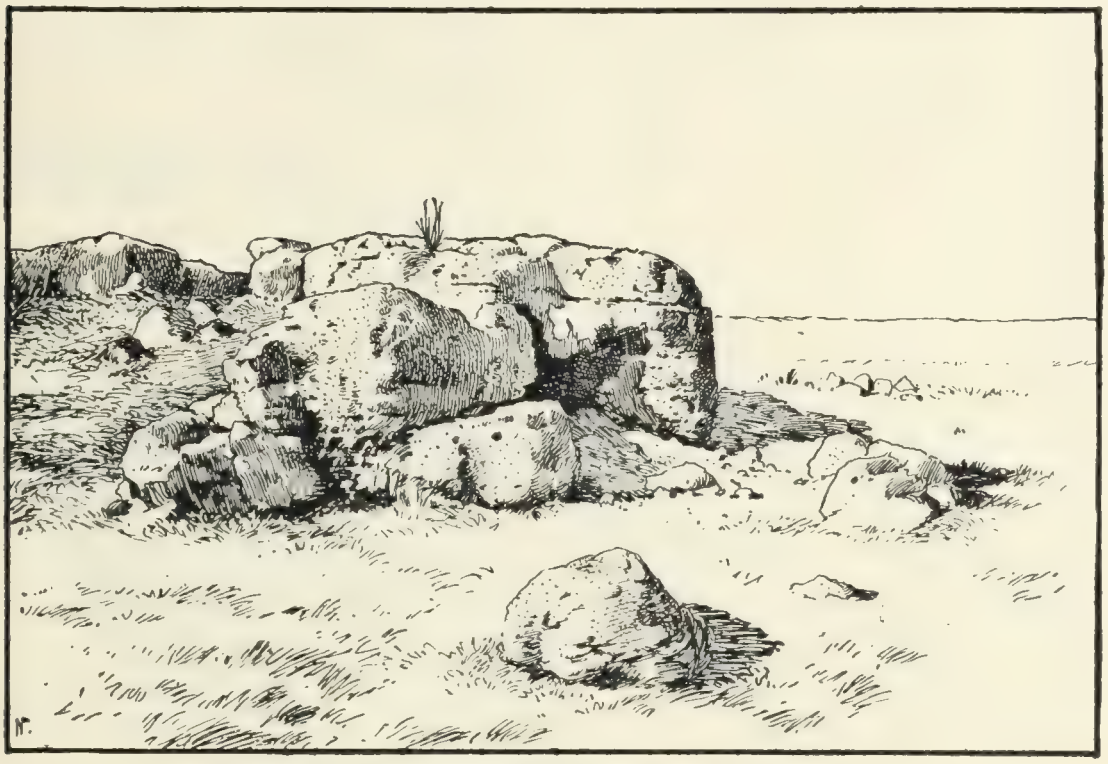


FIG. 62.—Outcrop of mortar-bed conglomerate—Tertiary grit.

bottom alternate among soft "magnesia," reddish calcareous clays, and two or three horizons of gravel or conglomerate; so the varied beds give the varied topography. The gravel hill topography is characteristic of both sides of the South Platte Valley from Ogallala to Julesburg. It is much less conspicuous in all the more southern valleys.

It has been said that a horizontal surface of the limestone or the grit gives a rougher appearance than the marl. These surfaces are mostly confined to slopes on the sides of the valleys and ravines, and break off suddenly in precipices of from 1 to 20 feet in depth. There are, however, some regions where the high prairie, nearly as level and smooth as if it were the Plains marl, has its floor composed of the "magnesia" underlying a shallow sedentary soil. An area of this kind stretches for some miles north and northeast of Cheyenne Wells, in Colorado. Another is

north and west of the head of Goose Creek, between the heads of the two forks of the Smoky River, in Kansas, and another is found in Deuel County, Nebr., north of Julesburg; and there is also a strip on both sides of the shallow depression of the South Beaver, both in Kansas and Colorado. The largest area, however, where this Tertiary formation—magnesia, gravel, or conglomerate—is at the surface is the district reaching from Imperial, in Chase County, Nebr., to and west of Holyoke, Colo., and from the Frenchman north nearly to the South Platte bluffs. It occupies a considerable part of four counties. On the railroad grade from Imperial to Holyoke shallow cuts show its presence, and it is prominent in every cut from Holyoke to Grant. Little gullies by the roadside are white with it. In parts the rougher mortar beds and conglomerates

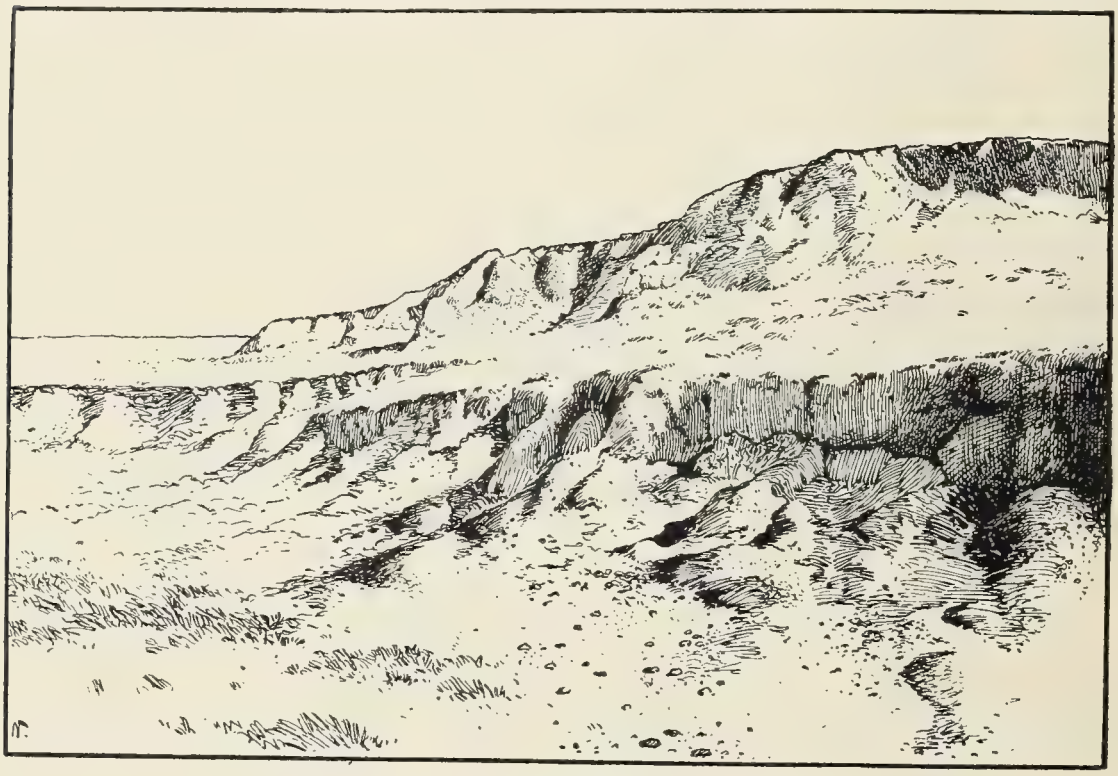


FIG. 63.—Tertiary grit under bluffs of Plains marl.

are present and the gentle slope of slight depressions shows the gravel. The traveler can recognize this, even in the dark, by the sound of gravel under the wheels. In one place, north by west of Venango, a deserted prairie-dog town simulates the rounded topography of the gravel hills northeast of Julesburg. The marmots had brought out of their holes much gravel, which has protected the little mounds from the winds, and they are now squat domes. There are hundreds of the domes scattered over parts of several sections of land. A similar but smaller dog town is seen on a creek bottom in Kansas.

This entire area with the Tertiary grit below the surface soil can not be less than 1,000 square miles, exclusive of the areas within the region where a thin sheet of the Plains marl remains. The northern edge of this district has a sheet of Plains marl above the grit, wedge-shaped,

but nowhere very thick, the thickest being at the breaks where the descent begins to the South Platte. The area thus described would be larger if certain stretches of sand hills were included. They rest on the surface of the grit, and in places low grit hills protrude from the sand and have sand buttressed against them.

This region of surface grit has an important bearing on the water supply of the plains, and in that connection the sand hills included have the same bearing; and we may reckon this as one area, extending from the north line of Perkins County, Nebr., to the Frenchman River south of Imperial, and reaching into Colorado 10 miles west of Holyoke. In parts these conditions prevail in a strip a mile or two wide south of the Frenchman. This gives a total of nearly 2,000 square miles within the region of this inquiry, and there is extension of some of the conditions both eastward into Nebraska and westward into Colorado.

The level parts of this region have basins like the Plains marl, and in these basins the sedentary soil is thicker, therefore smoother, and the grama and buffalo grasses (*Bouteloua oligostachya* and *Buchloë dactyloides*) have taken possession. A merely cursory examination will not distinguish these smoother districts from Plains marl areas. These basins, both in the grit and marl, are probably the relics of the last Tertiary and the post-Tertiary lakes.

TOPOGRAPHY OF THE CRETACEOUS BEDS.

It has been said that the Cretaceous formations underlie the whole region of this investigation, but they do not appear at the surface in either of the Platte valleys or at all north of the Frenchman. In the valleys of the three forks of the Republican, shales of the Fort Pierre epoch are conspicuous. In the district under consideration they do not show in any of the Beaver valleys or in the valley of the North Smoky Fork, but the South Fork of the Smoky and its tributaries show them again. How their eroded surfaces, hidden under the Tertiary formations, affect the present surface of these later beds is not sufficiently pertinent to the present inquiry to demand discussion. It is only where these shales outcrop that their topography concerns us here. Their influence on the water supply has already been mentioned. These shales in the Republican valleys are mostly clay-shales—some bluish, locally called soapstone, and others greenish or yellow. There are also some laminated carbonaceous shales. In the southern valleys the carbonaceous beds are more abundant, lying mostly below the argillaceous beds. Where the superincumbent Tertiary beds have been removed to any great extent—as in the Arikaree Valley and in that of the South Smoky, and farther west beyond the region of this investigation, from Hugo to Limon in Colorado—there are long, smooth slopes and areas, almost level, that simulate closely slopes and levels of the Plains marl, and Plains marl grasses cover them. In the Arikaree Valley in Arapahoe County, Colo., there are bench slopes that come down to the river bed, some of which are Plains marl and some Fort Pierre

shales. They have a gently rounded contour, and are to be distinguished only in the ruts or small gullies that traverse them or, in wet weather, by the tenacious mud of the shales. The matter of the shales, modified by weather and vegetation, is the adobe soil of the southwest. The interjection of adobe benches among benches of Plains marl is also seen in the valleys of the South Smoky in Wallace County, Kans.

In ravines the vertical section of the shales is very abrupt, and they also frequently appear as long and narrow ridges with rounded tops; sometimes these ridges have very rugged outlines, from the presence of hard, concretionary masses, which have preserved from erosion the softer parts beneath. A similar result has occurred where the Tertiary conglomerates or the mortar beds have rested on the shales; the harder slabs have fallen over and so prevented further undermining by preserving the shales. The ravines on the south side of the main valleys have therefore a very rugged, canyon topography. It has already been mentioned that the South Platte Valley, where the shales do not outcrop, is an exception in this region to the rule of ruggedness on the south side of valleys. The most northern outcrop of the shales in this region appears to be on Rock Creek, northeast from Haigler, Nebr.

TOPOGRAPHY OF THE SAND HILLS.

The manner of the formation of sand hills is frequently taken for granted. On a seacoast, where the sand derives its fineness from the wash of the waves, the presence of sand dunes near is doubtless due to the action of the wind on the shore between tides. Rivers far inland, with wide sandy beds in times of low water, also supply to the wind the means of building sand hills along their valleys. It is therefore generally assumed that these are the only ways in which the material of sand dunes is supplied. There are, however, regions where a closer examination suggests some other origin than those mentioned for the immense mass of material that forms large expanses of sand dunes, which, though in their parts mobile as other sands, are stationary in their own districts, encroaching, if at all, but slowly on adjacent country.

The region extending 15 to 20 miles on each side of the one hundred and second meridian between the Frenchman and the North Fork of the Republican River is one of these areas. It is not less than 1,000 square miles in extent. It has been noted above that the region north of this has mostly the Tertiary grit as its floor, with but thin soil on it. The residue left in situ after the weathering of the grit is gravel and sand. The gravel remains; the sand may be blown away after the lime and the clay have leached out. It has also been noticed that in parts the lower beds of the Plains marl are very arenaceous. The leaching of the cementing material of these sands would then be a short process, and the residual mass would be great. From such records of wells in this sand-hill region as are available we find that the Tertiary grit underlies the sand and that there are some sheets of clay in the sands. In the southern part it is inferable that the sands

rest on the Cretaceous shales, and it is not unlikely that this southern boundary is an encroachment of arenaceous material on the valley of the Republican.

The sand hills of this region may then be considered as the residuary material of the lower parts of the Plains marl and of the mortar beds of the Tertiary grit of the region itself, together with some wind-blown residue from the adjacent parts to the north and west, and it may be said that their encroaching borders are to the south and east. Encroachment, however, seems now to be at a minimum, as grasses have covered almost the entire area, but changes have taken place comparatively recently. Where roads have crossed the district the ruts formed have become a starting point for the wind, and wide chasms have been cut in the sands, which, in the section exposed, are seen to be closely packed. Sometimes the wind has cut a nearly vertical face with a curve almost as of an amphitheater. Such places are known as "blow-outs." The topography has also been changed in another way, by human agency. Contrary to the general impression, the sand hills are not the least valuable lands for agriculture. Many farms have been opened in their grassy valleys, and in the driest years—notably, 1890 and 1894—these farms have yielded the only agricultural products of the region, grain, forage, and potatoes. This is because of the fact that water exists in quantity only a few feet below the surface, and is available for the sustenance of plants. The farmer, however, has a serious difficulty to contend with, for when he has stripped off the surface of grass with his plow the wind again has the chance to work on the incoherent material, and the plowed field becomes a depression. The writer has seen whole fields depressed from 1 to 2 feet, and smaller areas swept out so deep that the process was stopped by the dampness of the sand, when marsh plants took possession of the bottom.

The prevalent forms in the sand hills are oval or oblong valleys surrounded by ridges, which are sharp or rounded according as they are less or more covered with vegetation. Some of these valleys are several hundred acres in extent. Then there are areas where the valleys are deep and small and most of the land is in ridges. Some of the oblong valleys form lines that become recognized toward the southern boundary of the district as creek valleys, which at their lower end have permanent running water. Such are Chief Creek in Colorado, and Buffalo Creek and Rock Creek in Nebraska.

Every valley in the region investigated has some areas of sand dunes, and on every plateau there are districts more or less arenaceous. These last are manifestly but recently formed, and the weathering of the Plains marl in adjacent draws and ravines is seen to be the cause. In several places on the Kansas-Colorado boundary the Plains marl is scarcely discolored at all by the vegetation, which can have been on it only a comparatively short time, and the wind still blows the sand from among the grass roots. It is a tradition of the plains that the early explorers reported these regions all sand which are now level stretches of buffalo sod.

THE WATER-BEARING FORMATIONS.

THE DEEPER BEDS.

The lowest Cretaceous formations—the Trinity sands—and beds of Jurassic or Triassic age might be expected to give some water, but in the region of this investigation they are too deeply buried to be available if their existence should be proved. The same is true also of the Dakota sandstones, which in the neighborhood of the Smoky Hill and Republican rivers could, however, probably be reached at a depth of less than 1,000 feet. In 1882 deep borings were made at Cheyenne Wells, at the southeastern corner of Cheyenne County, Colo., and at Akron, just outside its western boundary. Since then a boring nearly 1,000 feet deep has been made at Oberlin, to the east of the district. None of these give any encouragement to the expectation of a supply of good water from these deeper strata.

THE TERTIARY GRIT.

Beds included in this term are those containing the main body of the underground waters of the plains. The section of these beds as shown in the ravines of the south side of the North Platte, northwest of Ogallala, is as follows, this being beneath 170 feet of Tertiary marl:

Section of Tertiary grit along the North Platte northwest of Ogallala, Nebr.

	Feet.
1. White "magnesia" limestone	40
2. Reddish-brown, marly limestone	
3. Gravel but slightly cemented, 5 to 10 feet	
4. Rough, hard, mortar-bed grit	25
5. A softer layer	
6. Reddish, sandy, marly grit	
7. Pebbly grit, 3 or 4 feet	
8. White grit, weathering rough	40
9. Pebbly grit, a few feet	
10. Hard ledges with few pebbles	
11. Reddish clay with harder streaks, 3 feet	
12. Hard, whitish bed	35
13. Polishing powder	
14. Limy, whitish bed	80
15. Hard, white rock	
16. Faint cream-colored grit	
17. Hard, white rock	
18. Softer, white rock, 15 feet	
19. To river bed below Tertiary grit	240

The beds run into one another so much that it is difficult to separate them. An escarpment showing 15, 16, and 17 had also a bed of gravel halfway across. This is the condition of the outcrop at Spring ravine, in Mr. Follett's profile, and at Eagle ravine, which lies between the two. Beds 3, 7, and 9 give the hummocky, gravelly hills to the outcrop, but the interjection of gravel in No. 16 indicates that other levels may also supply gravel. The North Platte Valley is 80 feet lower than the valley of the South Platte, but neither of them cuts to the bottom of

these beds. A boring at Paxton, Nebr., 19 miles east of Ogallala, made by the Union Pacific Railway Company, continues the section downward thus:

Section at Paxton, Nebr.

	Feet.
Hard, red clay with hard, limy streaks and sand streaks, some several feet thick	100
Similar material with hard ledges 5 or 6 inches thick	58
Hard, white limestone	10
Red material with hard streaks	80
Total	248

It is evident that the gravels and sands of these beds can hold water if it can reach them. It is true that the mortar beds and many of the finer-grained limestones also absorb and retain a large proportion of water. The red clays, on the contrary, are to a great extent impervious and serve to separate the other strata into different water-bearing sheets. The section on the south of the South Platte is about as follows:

Section on south side of South Platte, down Italian Ravine from the high divide.

	Feet.
Plains marl soil	1 or 2
Gravel mounds down to level of spring (2)	60
Gravelly hummocks, probably including soft "magnesia" protected by the gravel	145
Hard limestone (porous), including one hard ledge 15 inches (quarried), others less, with obscure fossils	2
Pink "magnesia"	15
Greenish sand with turtle bones and hard, limy nodules	20
Other soft beds	31
White "magnesia" over Gibello Cave	20
The conglomerate of the upper cave, including the hard, slabby roof and spring at bottom	8
Ledge of hard "magnesia"	2
Softer "magnesia" to river bed, including the lower cave	30
Total	335

Farther south the bed of the Frenchman in the region under consideration is only a depression in these grit formations. Just east of the State line it has become deep enough to show permanent water, and less than 10 miles farther east it has become a perennial stream. The entire valley to near its mouth nowhere reaches the bottom of the grit. The case is different in the Republican valleys. The various forks of that stream have cut down at least 100 feet into the subjacent Cretaceous shales. At Wray, Colo., the exposed section on the south side of the valley is as follows, the north side being sand hills resting on shales:

Grit beds at Wray, Colo.

	Feet.
1. White, rough "magnesia," with some gravel	
2. Conglomerate, about 10 feet	
3. Pinkish mortar beds	120
4. Hard ledges	
5. Slope, presumably shale	

These beds begin more than 30 feet above the level of the depot at Wray, the slopes under being presumably shales and the alluvium of the valley. A few miles lower down the river, at Laird, the shales are plainly visible and the grit section is about the same in thickness. At both Laird and Wray there is a strip on the top of the bluffs having sedentary soil of the grit, giving place at a very short distance to the south to a sheet of the Plains marl, which in several places is found also in the valley. On the south side of the Arikaree the shales reach higher levels and the thickness of the grit section is not more than 30 feet. In Chimney Rock Canyon we have the appearance shown in fig. 64.

On the other hand, in places the grit rocks come down to the river, showing the pre-Neocene erosion of this valley. On the South Republican the grit is no thicker, but southward on the table-land from Good-

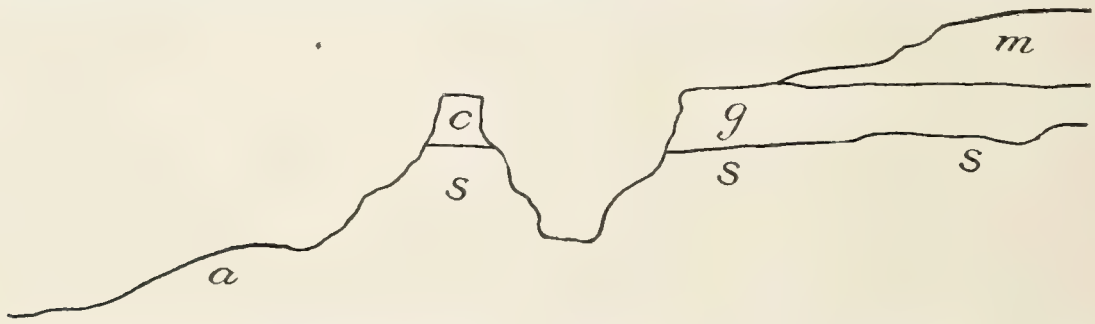


FIG. 64.—Diagram of stratification in Chimney Rock Canyon. *a*, alluvium; *c*, Chimney Rock; *g*, grit; *m*, Plains marl; *s*, Cretaceous shales.

land to Burlington it thickens considerably, again to thin out to the South Forks of the Smoky Hill.

The section as exhibited in the following wells in different parts of the country shows the similarity to the valley outcrops and indicates that the structural variations are also as great. These wells do not give the whole section; none of them go entirely through the grit.

Well No. 48 (Bull. 131, pp. 95, 101), NE. ¼ of sec. 13, T. 14 N., R. 42 W., in Deuel County, Nebr.

	Feet.
Soil	8
Yellowish clay (the Plains marl)	88
Sand and gravel (with water)	314
Clay	
"Magnesia" and gravel	
Rock	
"Magnesia" (water at 325 feet)	
Reddish "magnesia"	
Total	410

Water was 5 feet deep, but rose 95 feet higher.

Well No. 99 (Bull. 131, pp. 96, 105), Venango, Colo.

	Feet.
Soil	4
"Magnesia"	10
Red clay	30
Hard rock, shale (?), and gravel, with 40 feet of water	146
Total	190

Well No. 8 (Bull. 131, pp. 95, 97), Imperial, Nebr.

	Feet.
Surface soil	6
Whitish "magnesia"	
Red clay	106
Gravel, with 24 feet of water	
Total	112

Well No. 9 (Bull. 131, pp. 95, 97), at same place, is 123 feet deep and has 36 feet of water, in gravel; "hard ledge" just over the water.

Well No. 43 (Bull. 131, pp. 115, 119), Cheyenne County, Kans.

	Feet.
Soil	3
Yellow soil (Plains marl)	50
Sandy rock	10
Red clay	
Sand	110
Quicksand, containing 20 feet of water	
Total	173

Well No. 8 (Bull. 131, pp. 106, 108), Arapahoe County, Colo.

	Feet.
Soil	2
Yellow marl (the Plains marl)	35
"Magnesia"	20
Rock, "magnesia" with ledges	14
Sand, with rock streaks	30
Hard, reddish clay (with bones)	
Sand	123
Sand and clay, with 4 feet of water and a little gravel	
Total	224

Well No. 61 (Bull. 131, pp. 115, 121), Goodland, Kans. (Rock Island Railway).

	Feet.
Soil	5
Creamy clay (the Plains marl)	30
Reddish clay, with streaks of sand	122
Gravel, with 9 feet of water	19
Total	176

Well No. 94 (Bull. 131, pp. 115, 124), on same half section in the town, is 181 feet deep and has 40 feet of water.

Well No. 118 (Bull, 131, pp. 116, 126), Wallace County, Kans.

	Feet.
Soil	3
Creamy clay (the Plains marl)	23
"Magnesia"	4
Running gravel	16
Rock and sand, with 12 feet of water	84
Total	130

One of these well records shows the finding of bones. Drillers in Chase County, Nebr., say they always get bones near Imperial, just above the water. In the North Platte outcrop the jaw of a horse has

been taken from the mortar beds, and in the South Smoky outcrop bones of both rhinoceros and mastodon have been exhumed. In other places many other fossils have been found. Possibly a full study of these will sometime give the exact relative age of the beds, but the irregularity of the beds themselves is well illustrated by these sections from different counties visited in the investigation.

Some of the well records show a streak of water—sometimes two—above the main supply. This is found in one or two of the streaks of sand or gravel shown in the sections. A complete discussion of well records will show what the above examples illustrate: that all the wells on the high prairie of the region investigated obtain their water from some horizon in the Tertiary grit.

THE PLAINS MARL.

As a water-holder the Plains marl is not a conspicuous agent. Its lower parts being sometimes more arenaceous, it does yield water in a few wells, but its main function is to act as a cover to the Tertiary grit, and it parts very slowly with the water it does imbibe. In the recent dry season examination of the vertical bluffs of the marl on the North Platte, the South Smoky, and several places between, where the surface had dried to a whitish, almost impalpable powder, locally called "flour soil," showed that 3 or 4 inches within the bluff face there was dampness, perceptible to both sight and touch. No rain or dew had fallen upon these surfaces for many months.

RIVER ALLUVIUM.

The bottom lands, both of the rivers and smaller streams, have an important relation to the water supply of the valleys. These bottoms are formed of the débris of the rocks of the valleys above them. The immense quantity of sand and gravel in the Tertiary grit and in the Plains marl which has been cut away by the erosion of ages has been largely redeposited in the valleys. The argillaceous constituents of these rocks and of the Cretaceous shales have also been drawn on to form the valley alluvium. This alluvium, then, is largely made up of layers of sand and beds of clay. Both the one and the other have formed the surface of flood plains, and so become changed into humus, or black soil, by the action of vegetation. Afterward they have been covered again with alluvium and the process has been repeated. Now these beds of alluvium are being again cut down, and the vertical section exposed shows sometimes half a dozen alternations of black soil with arenaceous or clay deposits. This alluvium, spreading over the valley and giving it a generally even contour, varies much in total depth. Not only do the side valleys differ in this respect from the larger ones, but the alluvium differs in depth in the same valley. This fact is important, but a discussion of the reasons for it is not pertinent to the main subject of this investigation.

How deep this alluvium is in any given district is rarely known, for the reason that wells sunk in it seldom reach the bed-rock of the river valley. The sinkers of wells are satisfied with a good supply of water. The boring at Paxton shows that the alluvium of the South Platte Valley is 90 feet thick, two-thirds of which is clay of the varieties called by the local drillers "hardpan." In the valley of the Arikaree there are places where alluvium reaches a thickness of 30 feet, and other places that look like the same bottom land where there is no alluvium of any sort, the appearance of the weathered surface of the subjacent shales simulating that of the bottom lands. This is repeated in the South Republican, and in these forks the alluvium nowhere much exceeds 20 feet in depth. Similar phenomena occur in the valleys of the forks of the Smoky Hill River. Alluvium is not thick in the various narrow Beaver valleys, but in this region it is not because of the presence of the shales, but because erosion has not proceeded far enough in the Tertiary formations. Roughly speaking, the broader the valley the deeper the alluvium.

The great prevalence of sand in these valleys makes these beds of alluvium great reservoirs of water. Sometimes one-sixth of the volume is water. Sandy alluvium 30 feet deep would, therefore, contain 5 feet of water. The clay beds serve in many parts to separate strata of sand—veins of water—and to prevent surface water from reaching the lower beds without considerable percolation and therefore filtering, so that deeper waters are the purest.

Many of the watercourses, even of the larger rivers, do not carry any stream for the greater part of each year; so the dry beds become drains to carry away the waters of the circumjacent alluvium. On the other hand, when the floods come, the high water in the channel serves to replenish the water supply under the bottom lands.

It has been shown how largely the waters of these valley lands are of economic value. It is here noted that they are an important part of the water supply, as the total area of the bottom lands is considerable. Again, water is found under the sands of the river beds themselves, even at their driest stage. The sinking of a bottomless barrel will make a well in such places, and a depression scooped out a few feet deep will furnish from the so-called underflow an abundance of water for the supply of cattle.

UTILIZATION OF WATER SUPPLY.

It is not the province of this investigation to indicate methods of using the water for irrigation and other purposes, but the facts observed may have influence in deciding points in the problems presented to the settler. Five years ago there were only two or three irrigation ditches in the region of this investigation—one southeast of Sharon Springs, another at Nesbits, west of Benkelman, and one at Wray. Now all the water of Rose Creek is used for irrigation. No ditch took water from

the Frenchman; now two ditches capable of irrigating several thousand acres of land are in this district, and there are two others farther east. In the Platte valleys no work was done with the water; now a ditch 3 miles long irrigates from the North Platte several hundred acres of land, and several pumping plants furnish water to from 5 to 20 acres each from the shallow wells of the South Platte Valley. The North Fork of the Republican has ditches above and below Wray and near Benkelman. Some irrigation is done on the Arikaree, and ditches on the South Fork of the Republican, taking underflow as well as visible water, carry about 800 to 1,000 second-feet, and a considerable area was irrigated in Cheyenne County, Kans., from this source in 1894. At a point a short distance above Presley, water of the North Fork of the Smoky is also used as soon as it makes its appearance.

The most important problem in this region is involved in the question: Can the high prairies be irrigated? A bold attempt is being made to carry the underflow of the South Platte about a hundred miles to the high level of Perkins County, Nebr. One of the South Republican ditches runs high up the slopes of the Cheyenne County plateau. Neither of these has yet shown that there is a sufficient volume of underflow for so long a journey. They will perhaps not be completed in 1895. On the other hand, in Wallace, Sherman, and Cheyenne counties, Kans., in Cheyenne, Kit Carson, Arapahoe, and Yuma counties, Colo., and in Chase County, Nebr., attempts have been made to irrigate from wells. It is claimed that the temperature of the water fresh from underground is too low for irrigation in the hot months. For this reason and because of the necessity of having a volume of water when irrigation is needed, earthen reservoirs, as shown by figs. 59 and 60, are being built in great numbers, varying in size from 25 to 200 feet square. Some have already successfully irrigated from a quarter of an acre to 5 acres. There are some preparations for irrigating from 10 to 20 acres in this way. Where wells are less than 100 feet deep there seems to be no doubt that sufficient water can be raised for this purpose. In Sherman County irrigators have demonstrated that mechanical difficulties will not prevent lifting water in quantity from depths even as great as 150 feet. In the regions of deeper wells the problem of overcoming the mechanical difficulties is the important one. It appears that there is water sufficient for irrigating areas of from 3 to 20 acres in every quarter section of the highlands. Such an amount of irrigation would be a practical redemption of the whole country from the consequences of its frequent seasons of deficient rainfall.

GENERAL SUMMARY.

It has been shown that the water supply of this region is limited as to immediate sources and yet is abundant in quantity. It can not be expected that the deeper-seated rock strata will give water by artesian or other wells in quantities equal to the surface necessities of the plains. On the other hand, certain Tertiary strata, herein called

the Tertiary grit, lying under the highlands of the plains at depths of from less than 100 to over 300 feet, hold a large supply of water.

The plains themselves are separated into table-lands by deep river valleys, and though there is a general similarity of conditions among these table lands, the wells upon them differ somewhat in depth. The more northern plateaus have the deepest wells. On all plateaus the depth of the water in the wells varies from 5 to 40 feet, the main reason for the variation being that most wells are stopped when the driller is satisfied that there is enough water for immediate purposes.

The waters of the valley bottoms are mostly of depth to be within the reach of an ordinary suction pump, and in all the valleys of this region they seem to be so abundant as to be practically inexhaustible, the motion of the so-called underflow being east and comparatively rapid in the loose alluvium. There are also areas in many of the valleys having water under second or even higher bottom lands and slopes at depths of from 40 to 70 or 80 feet.

The Republican valleys, the South Smoky, and some others farther

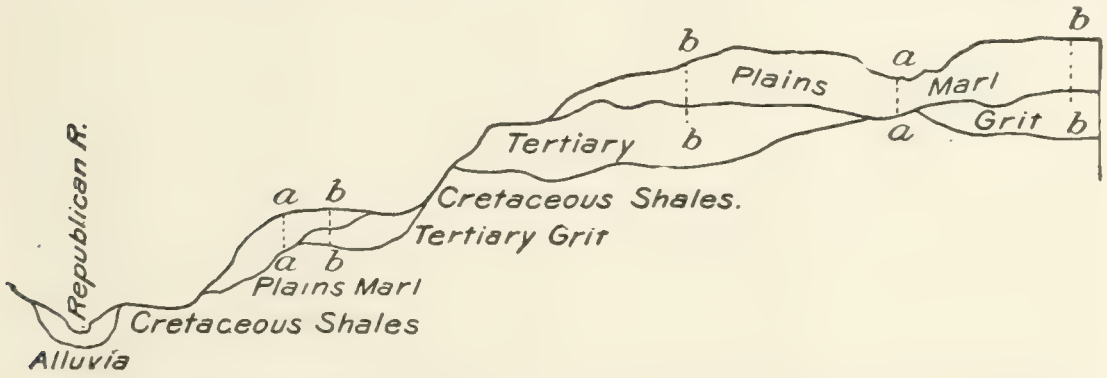


FIG. 65.—Generalized section from the Republican River near Haigler, Nebr., south into Cheyenne County, Kans. *a..a*, waterless wells; *b..b*, wells in Tertiary grit with abundant water.

east have outcrops of Cretaceous shales which limit the depth of the valley alluvium, and as they go under the adjacent plateaus they restrict the depth at which the water is found in the Tertiary strata above them. Occasionally wells on the upland, in Cheyenne and Wallace counties, Kans., and in Arapahoe County, Colo., reach the shales without passing through the grit, and such wells have no water, or very little.

The ultimate source of the water is the rainfall, and it has been shown that some large areas north of the Frenchman, and again on the Kansas-Colorado boundary north of the Smoky rivers, have exposures of the porous strata of the grit at the surface, and that therefore they absorb a very large proportion of the rainfall and pass it down to the water-holding strata above the underlying Cretaceous shales. Besides these, there are highly absorptive areas of the river valleys, on their right banks, which may pass the imbibed rainfall down the dip of the strata under the plains.

The irrigation of the valley lands by pumping the underflow seems now altogether feasible. On higher lands it has been energetically

undertaken, and in Sherman County, Kans., scores of irrigation plants raising water over 100 feet demonstrate their value. Some attempts are being made to get water from depths of 170 to 250 feet, and the mechanical difficulties, which are constantly being lessened, are the only obstacles to the irrigation of several acres of each upland farm from deep wells.

As to storage of storm waters, it may be said in general that where the underground waters are least available the facilities for such storage are most abundant. Such storage regions increase in area eastward, and the rainfall also increases in the same direction.

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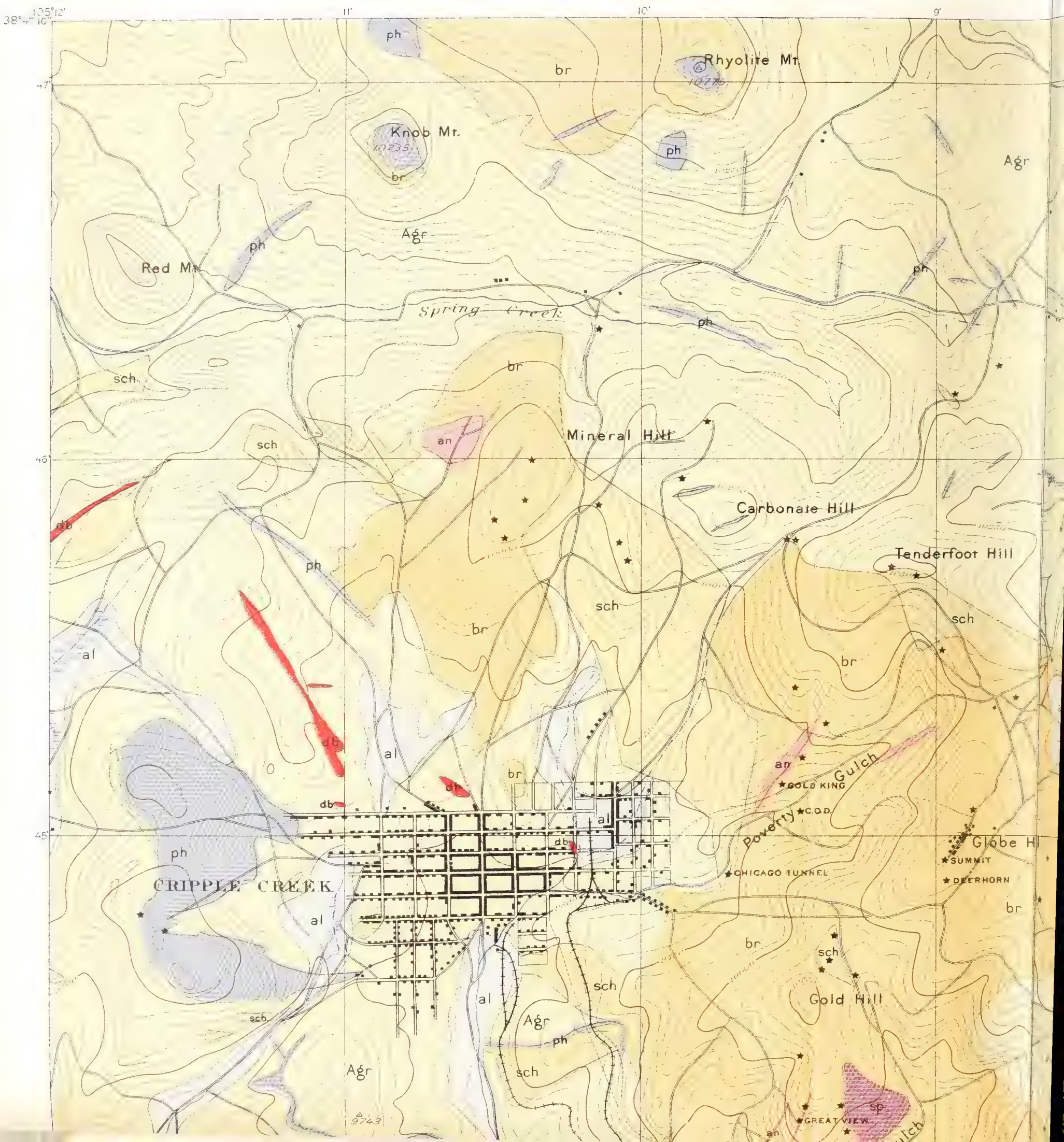
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C.O.D.
Poverty Gulch
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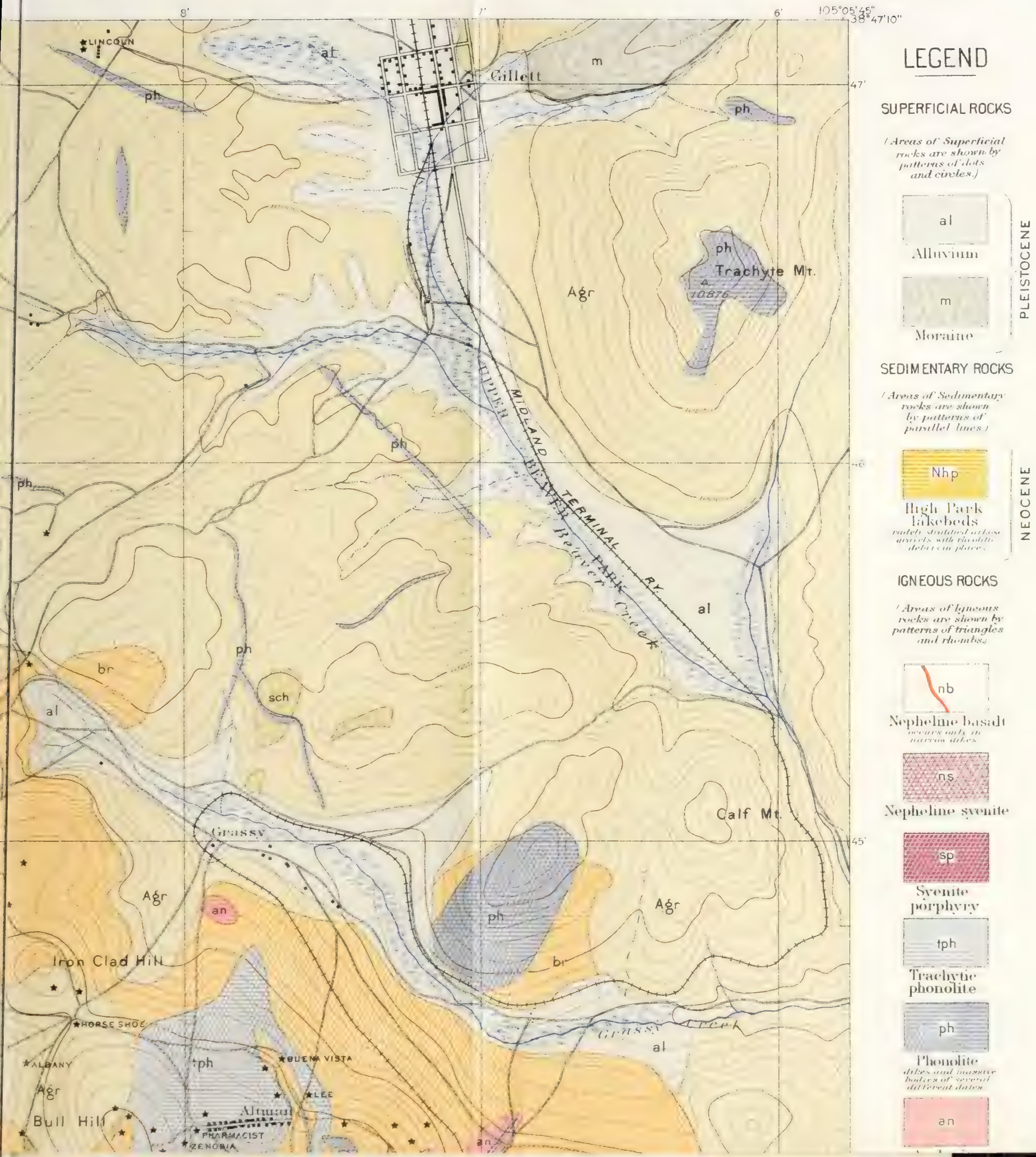
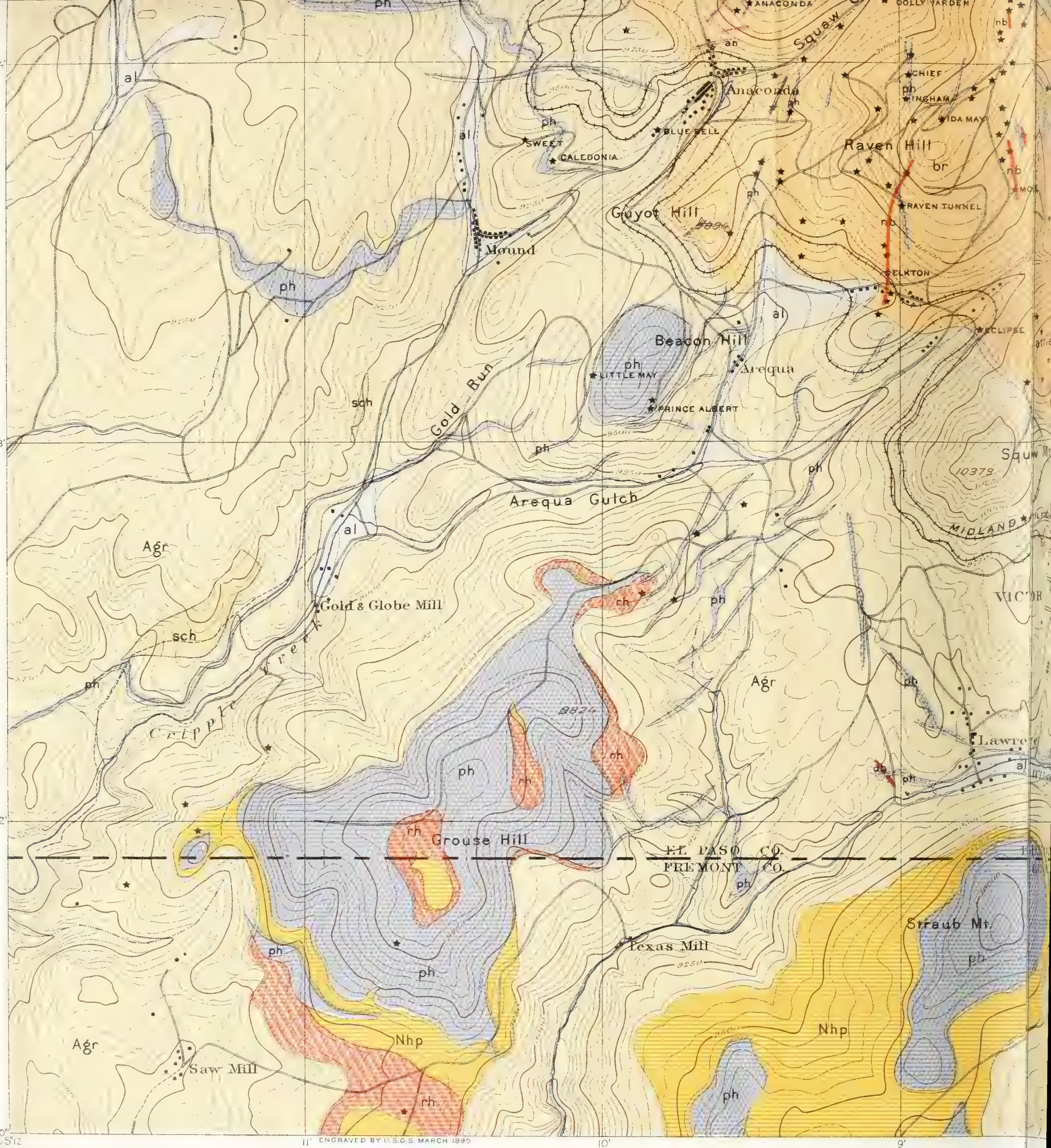
COLORADO

CRIPPLE CREEK SPECIAL MAP

TO ACCOMPANY THE SIXTEENTH ANNUAL REPORT, PART II.





ENGRAVED BY U.S.G.S. MARCH 1895

Henry Gannett, Chief Topographer
Triangulation by E. M. Douglas.
Topography by W. B. Corse T. M. Bannon and E. M. Douglas.
Surveyed in 1894.

Scale $\frac{1}{25000}$

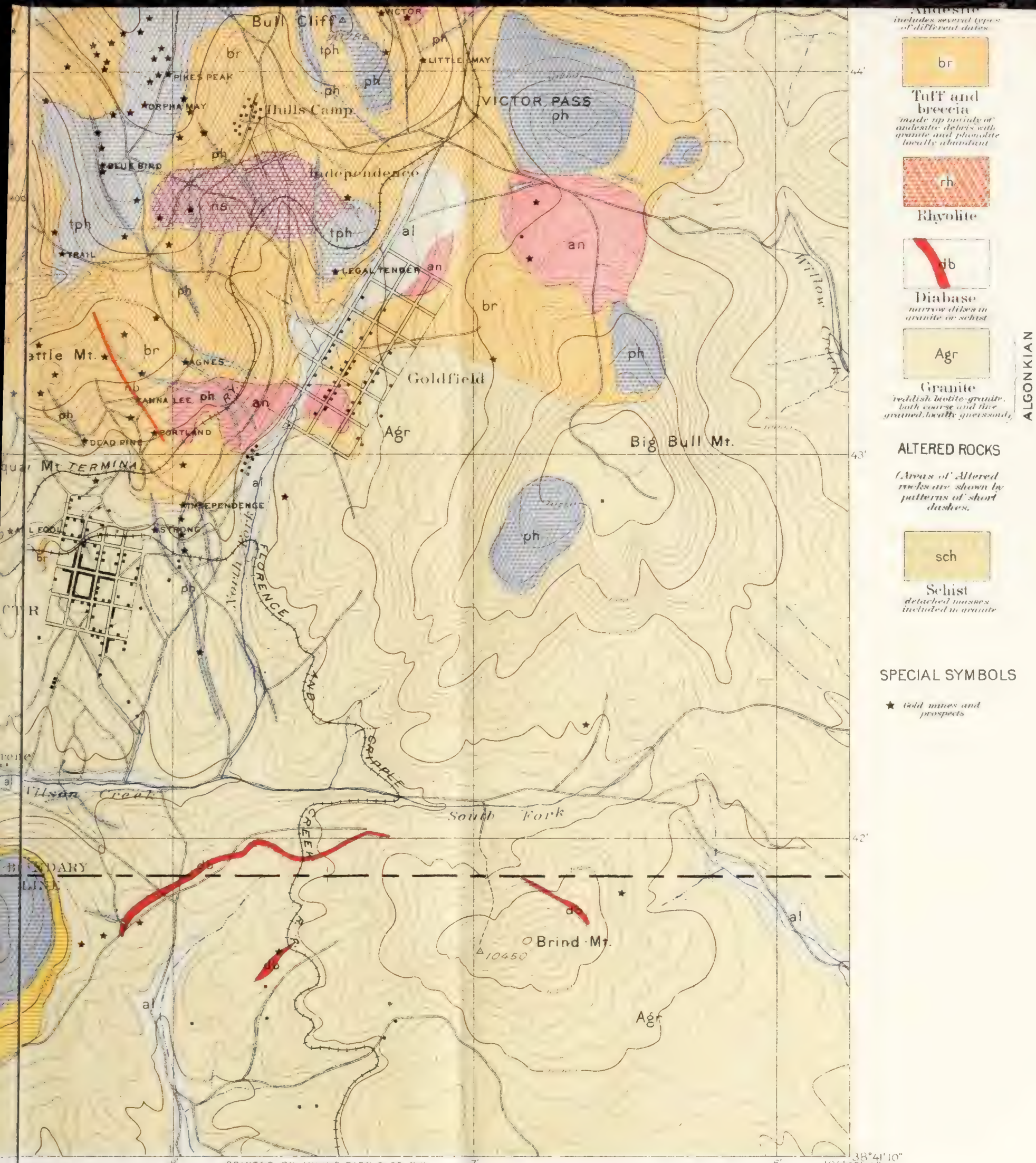
1000 500 0 1000 2000 3000 4000 5000 6000

Contour Interval 50 feet

Datum is mean Sea level

Initial position is Pikes Peak as determined by Hayden Sur

(From the Pikes Peak Folio of the Geologic Atlas of the United S



Geology by Whitman Cross.
E.B. Mathews, Geological Assistant
Surveyed in 1894

1 Miles

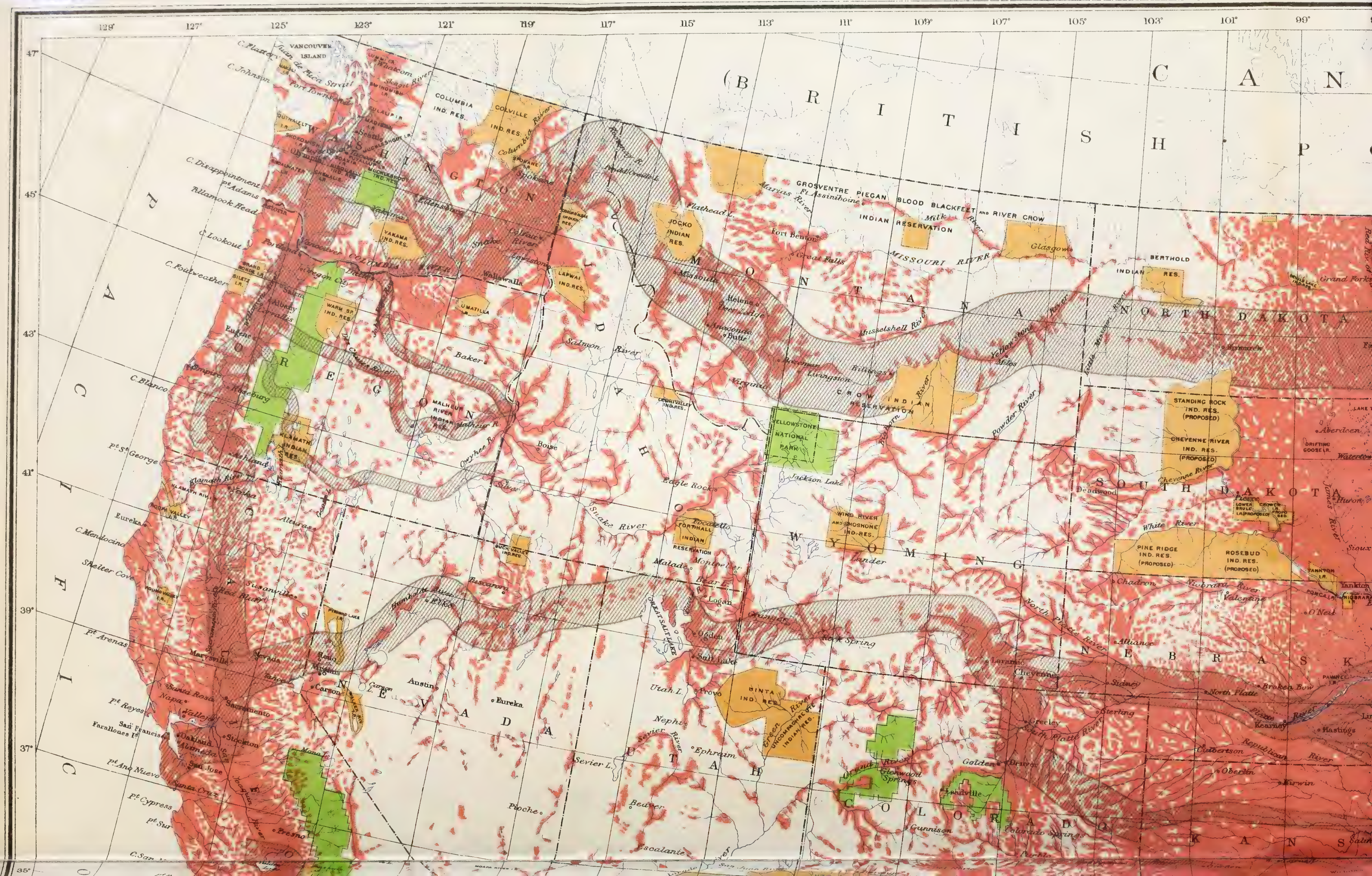
7000 8000 9000 10000 Feet

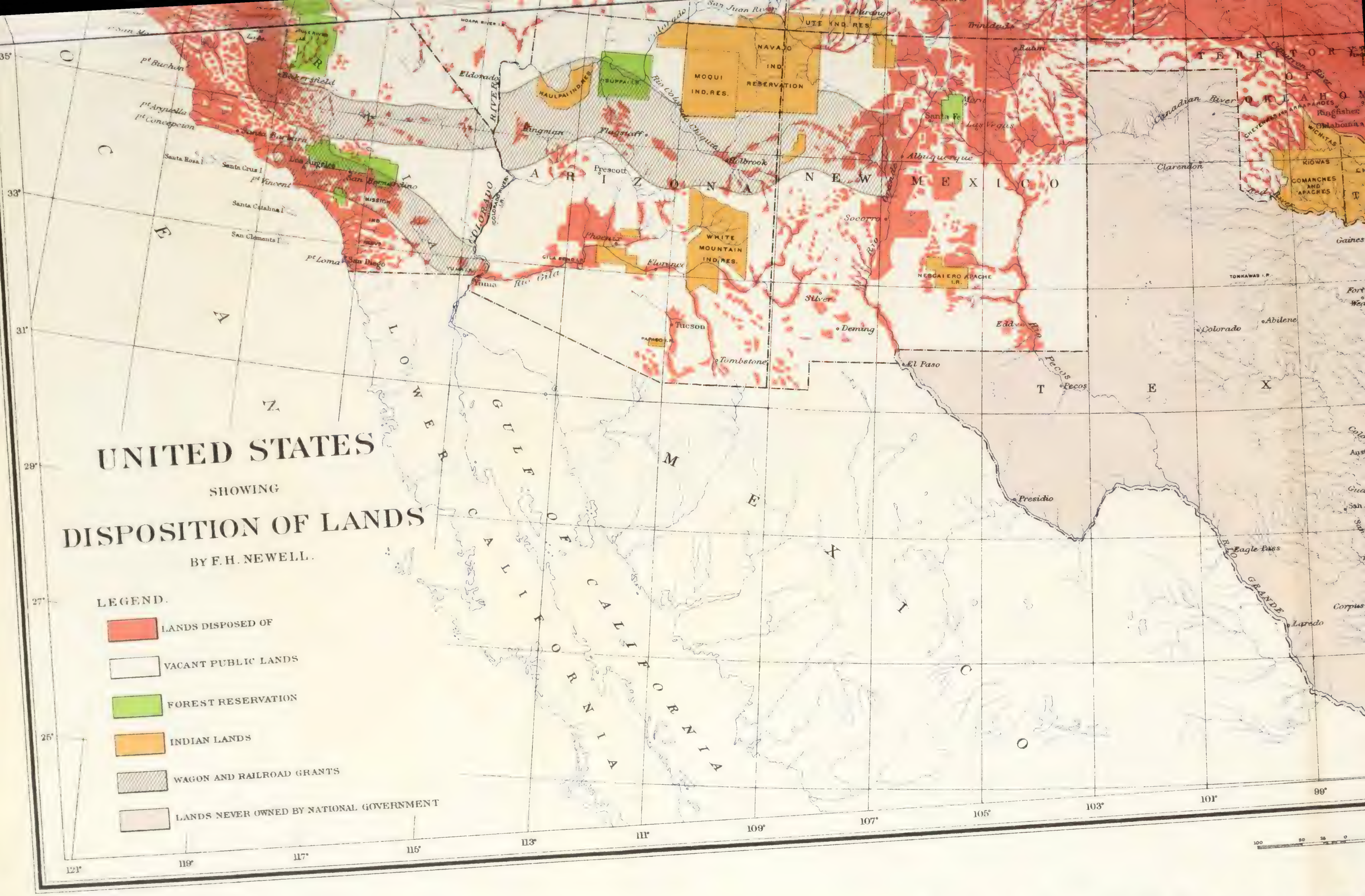
2 Kilometers

...ded Survey

...nit States, Edition of May 1895.

U.S. GEOLOGICAL SURVEY




UNITED STATES
SHOWING
DISPOSITION OF LANDS
BY F. H. NEWELL.
LEGEND.
LANDS DISPOSED OF
VACANT PUBLIC LANDS
FOREST RESERVATION
INDIAN LANDS
WAGON AND RAILROAD GRANTS
LANDS NEVER OWNED BY NATIONAL GOVERNMENT
ARIZONA
NEW MEXICO
TEXAS
CALIFORNIA
LOWER CALIFORNIA
GULF OF CALIFORNIA
MEXICO
TERRITORY OF OKLAHOMA
MOQUI IND. RES.
NAVAJO IND. RESERVATION
WHITE MOUNTAIN IND. RES.
NESCALERO APACHE I.R.
UTE IND. RES.
HAULPAI IND. RES.
SUPPAI I.R.
MISSION IND.
COLORADO RIVER
Rio Colorado Chiquito
Rio Gila
Rio Pecos
Rio Grande
Canadian River
Pt Buchon
Pt Arguella
Pt Concepcion
Santa Barbara
Santa Rosa I.
Santa Cruz I.
Pt Vincent
Santa Catalina I.
San Clemente I.
Pt Loma
San Diego
Los Angeles
San Bernardino
Bakersfield
Eldorado
Kingman
Flagstaff
Prescott
Phoenix
Florence
Tucson
Tombstone
Holbrook
Albuquerque
Santa Fe
Las Vegas
Socorro
Silver
Deming
El Paso
Pecos
Presidio
Eagle Pass
Laredo
Corpus
Colorado
Abilene
Clarendon
Gaines
Kingfisher
Oklahoma
Trinidad
Durango
Raton
Yuma
35°
33°
31°
29°
27°
25°
121°
119°
117°
115°
113°
111°
109°
107°
105°
103°
101°
99°

95° 93° 91° 89° 87° 85° 83° 81° 79° 77° 75° 73° 71° 69° 67° 65°
47° 45° 43° 41° 39° 37°
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ST. LAWRENCE RIVER
GEORGIAN BAY
GREEN BAY
SAGINAW BAY
Lake of the Woods
RED LAKE INDIAN LANDS
UNCEDED INDIAN LANDS
BOIS FORTS I.R.
DEER CREEK I.R.
VERMILLION LAKE I.R.
WINNEBEGOSHISH I.R.
CASS LAKE
WHITE EARTH INDIES
Leech L.
Pigeon R.
GRAND PORTAGE I.R.
ISLE ROYAL
Keweenaw Pt.
Houghton
Pt. Abbaye
Pt. Au Sable
White Fish Pt.
Sault St. Marie
Marquette
Ishpeming
Escanaba
Duluth
Superior
Moorhead
Mille Lacs
MILLE LAC I.R.
FOND DU LAC I.R.
LA POINTE I.R.
OTTONAGON I.R.
WISCONSIN STATE PARKS
Menominee
Green Bay
Appleton
Oshkosh
Manitowoc
Manistee
Grand Pt. Sable
Little Pt. Sable
Muskegon
Grand Rapids
Bay City
Saginaw
Alpena
North Pt.
Port Huron
Flint
Lansing
Detroit
Ann Arbor
Jackson
Battle Creek
Kalamazoo
Adrian
Toledo
Sandusky
Cleveland
Akron
Youngstown
Canton
Fremont
Tiffin
Mansfield
Elkhart
South Bend
La Porte
Fort Wayne
Lima
Logansport
Lafayette
Richmond
Indianapolis
Terre Haute
Danville
Decatur
Springfield
Jacksonville
Quincy
Hannibal
Louisiana
Moberly
Kansas City
Leavenworth
St. Joseph
Atchison
Topeka
Lawrence
Sedalia
Jefferson
St. Charles
St. Louis
Belleville
Alton
Vincennes
New Albany
Frankfort
Louisville
Lexington
Paris
Maysville
Huntington
Portsmouth
Ironton
Cincinnati
Newport
Covington
Madison
Hamilton
Dayton
Xenia
Springfield
Columbus
Circleville
Chillicothe
Lancaster
Zanesville
Newark
Delaware
Urbana
Piqua
Steubenville
Bellaire
Wheeling
Parkersburg
Clarksburg
Grafton
Charleston
Staunton
Lynchburg
Harrisonburg
Fredericksburg
Charlottesville
Richmond
Petersburg
Farmville
Manchester
Lexington
Hampton
Norfolk
Portsmouth
Eastville
Charles
Henry
Washington
Alexandria
Winchester
Cumberland
Hagerstown
Frederick
Baltimore
Annapolis
Easton
Dover
Seaford
Pt. Lookout
Cape May
C. May
Henlopen
Atlantic
Salem
Newcastle
Wilmington
Chester
Philadelphia
Norristown
Burlington
Camden
Trenton
Princeton
New Brunswick
Elizabeth
Phillipsburg
Easton
Allentown
Reading
Lebanon
Pottsville
Harrisburg
Altoona
Williamsport
Danville
Shamokin
Shenandoah
Mauch Chunk
Scranton
Wilkesbarre
Carbondale
Bradford
Erie
Meadville
Titusville
Pittsburg
Allegheny
Connellsville
Cumberland
Brooklyn
New York
Staten Id.
Long Branch
Barnegat Inlet
Sag Harbor
Montauk Pt.
Bridgeport
New Haven
New London
Norwich
Waterbury
Meriden
Hartford
Springfield
Worcester
Holyoke
Greenfield
Cambridge
Boston
Lowell
Lawrence
Salem
Gloucester
C. Ann
C. Cod
Monomoy Pt.
Nantucket
Martha's Vineyard
Pittsfield
Albany
Troy
Schenectady
Amsterdam
Saratoga Springs
Utica
Rome
Oswego
Syracuse
Auburn
Rochester
Lockport
Buffalo
Niagara Falls
Ithaca
Elmira
Binghamton
Kingston
Poughkeepsie
Newburg
Watertown
Ogdensburg
St. Regis I.R.
Lake Champlain
Burlington
Montpelier
Rutland
Concord
Dover
Portsmouth
Rochester
Manchester
Nashua
Lowell
Lawrence
Gloucester
Boston
Cambridge
Greenfield
Springfield
Worcester
Holyoke
Hartford
Meriden
New Haven
New London
Norwich
Waterbury
Bridgeport
Newport
Providence
Bangor
Belfast
Rockland
Pemaquid Pt.
Augusta
Lewiston
Bath
Portland
C. Elizabeth
Biddeford
Saco
Auburn
Calais
Schoodic Pt.
Penobscot River
Kennebec R.
Sioux
Dubuque
Galena
Freeport
Rockford
Elgin
Chicago
Aurora
Joliet
Michigan City
Janesville
Madison
Milwaukee
Racine
Waterloo
Marshall
Cedar Rapids
Des Moines
Iowa City
Davenport
Muscatine
Rock Island
Lasalle
Ottawa
Galesburg
Peoria
Bloomington
Burlington
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Keokuk
Creston
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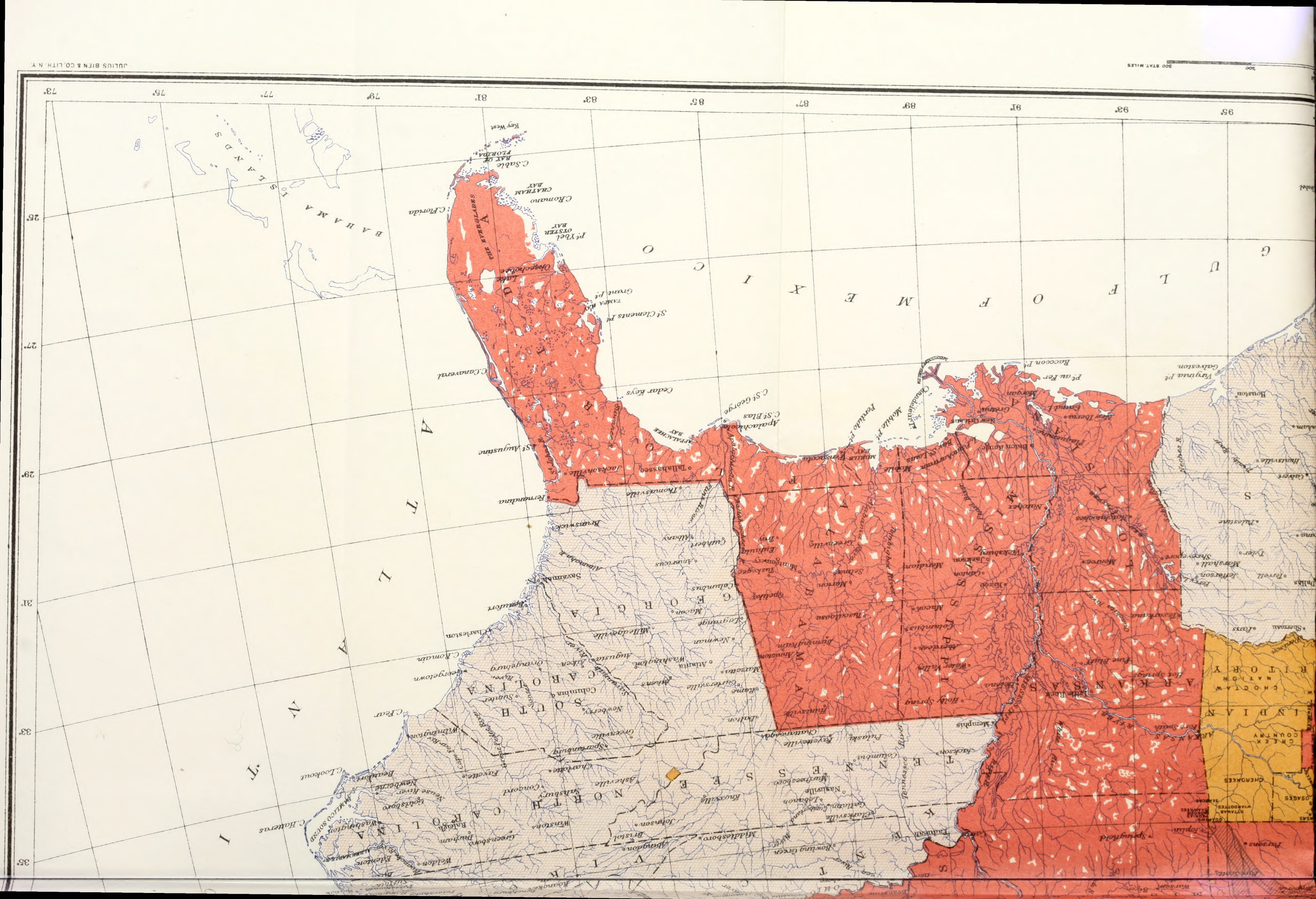
Council Bluffs
Omaha
Nebraska
Beatrice
Quincy
Springfield
Decatur
Jacksonville


JULIUS BIEN & CO. LITH. N.Y.
300 STAT. MILES
GULF OF MEXICO
ATLANTIC OCEAN
BAHAMA ISLANDS
FLORIDA
THE EVERGLADES
Key West
C. Sable
BAY OF FLORIDA
CHATHAM BAY
C. Romano
Pt. Yhel OYSTER BAY
C. Florida
Lake Okeechobee
Tampa Bay
Grant Pt.
St. Clements Pt.
C. Canaveral
Cedar Keys
C. St. Blas
C. St. George
Apalachicola
APALACHEE BAY
St. Augustine
Tallahassee
Jacksonville
Mobile
MOBILE BAY
Mobile Pt.
Berthe Pt.
Chandeleur
Pt. au Fer
Raccoon Pt.
Vermilion Pt.
Galveston
Houston
Sabine R.
Neches R.
Trinity R.
Galveston Bay
Huntsville
Calvert
Bryan
Palestine
Tyler
Marshall
Shreveport
Natchez
Vicksburg
Monroe
Jackson
Meridian
Montgomery
Selma
Eufaula
Tuskegee
Columbus
Macon
Augusta
Savannah
Brunswick
Thomasville
Tallahassee
Pensacola
Mobile
Montgomery
Atlanta
Augusta
Charleston
Savannah
Beaufort
Wilmington
Raleigh
Goldsboro
Newbern
Washington
Edenton
Norfolk
Richmond
Petersburg
Lynchburg
Staunton
Harrisonburg
Winchester
Cumberland
Wheeling
Pittsburg
Cincinnati
Louisville
Nashville
Chattanooga
Knoxville
Memphis
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Bangor
Halifax
Quebec
Montreal
Ottawa
Toronto
Kingston
Hamilton
Sandusky
Erie
Pittsburg
Harrisburg
Philadelphia
Baltimore
Washington
Annapolis
Dover
Trenton
Newark
New York
Hartford
Providence
Newport